METAL PROGRESS

APRIL

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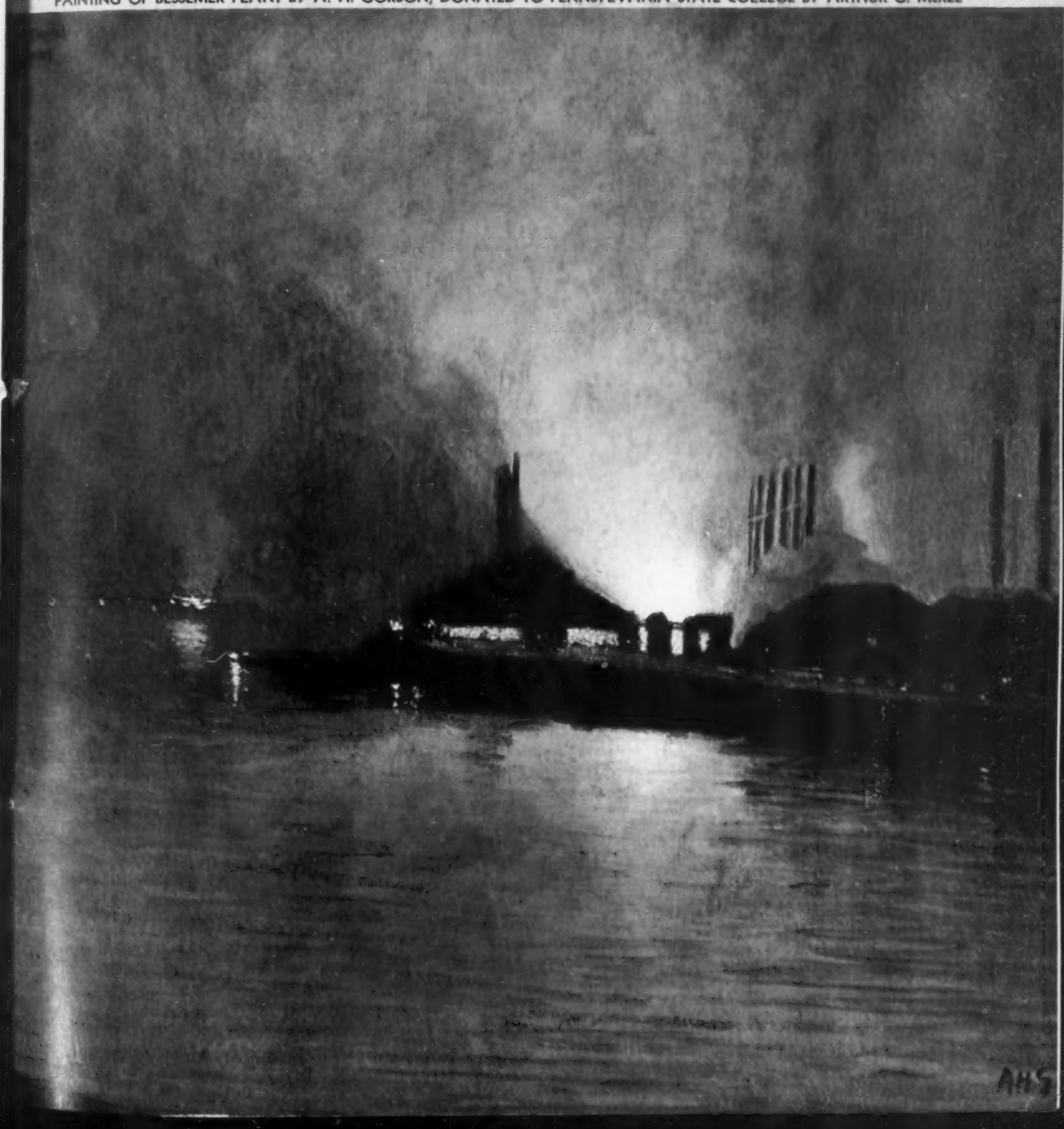

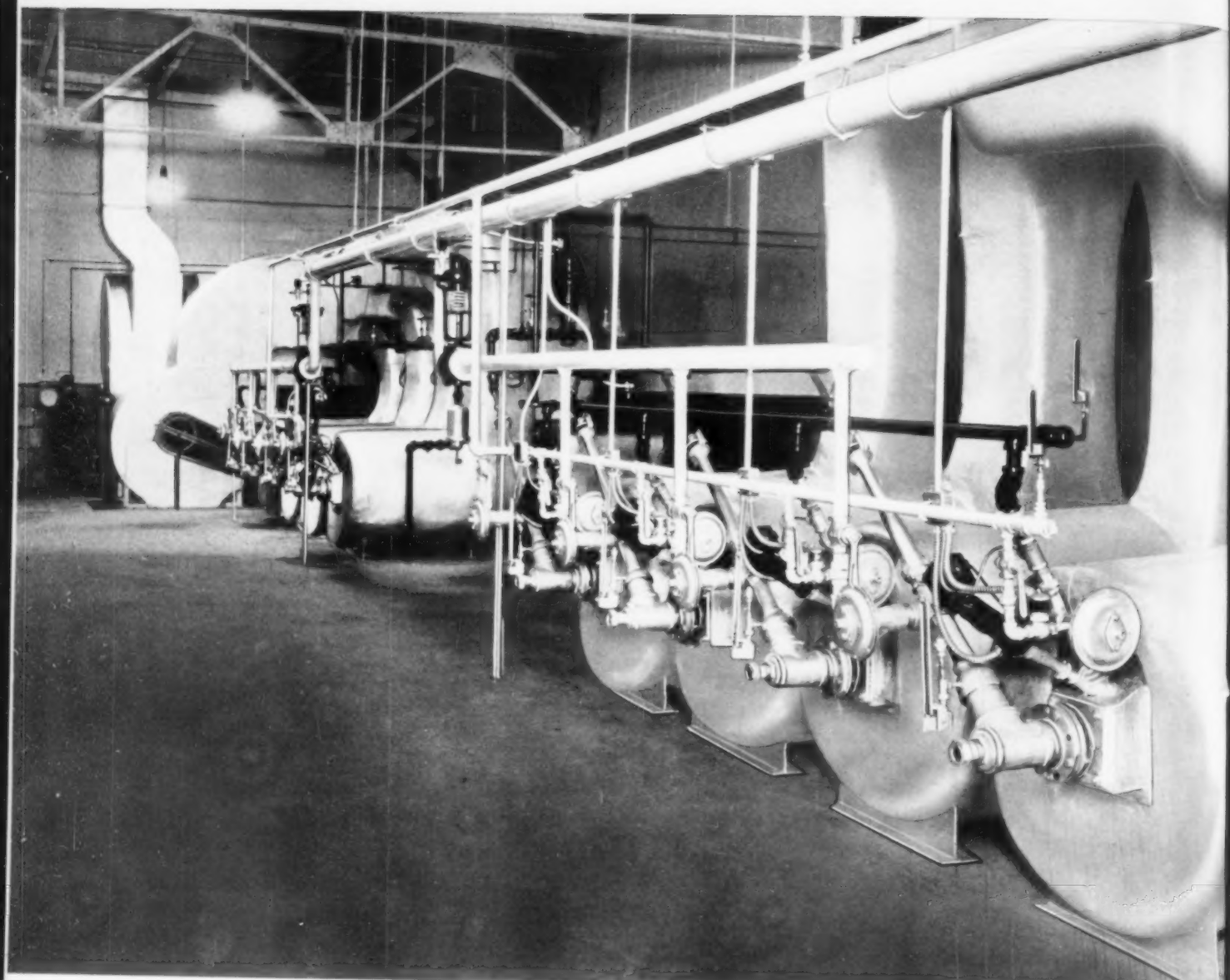

● Eight SC direct-fired air heaters shown here in a great motor car body building plant, are used for supplying heat to ovens for quick drying of prime, glaze, and finish coats of paint on 100 automobile bodies per hour. The net heat input for this purpose is 8,000,000 B.T.U. per hour. In the same plant, 24 SC air heaters are used for "making up" fresh air to replace the air used to draw fumes from spray painting booths for protection to health of the workmen. Air heated to 84° F. from these air heaters forms a "curtain" between the operator and his work. No portion of this air is re-circulated. Capacity of these 24 air heaters is 48,000,000 B.T.U. per hour. Similar equipment has been installed in other large body plants.

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Published by the American Society for Metals

Metal Progress

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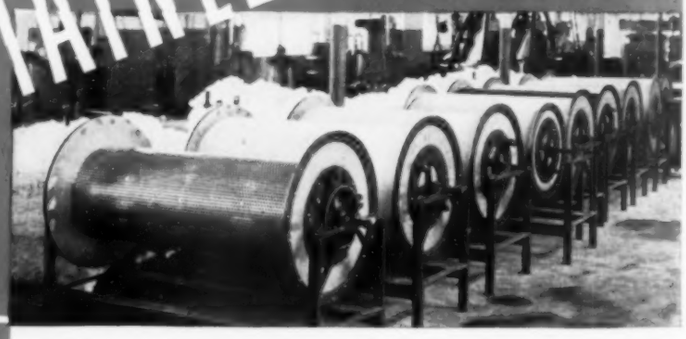

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Metal Progress

Volume 33, Number 4

Doctor Jeffries Views the Progress in Tools

Evolution of Tool Materials

WE HAVE ALL READ OF THE PROFOUND EFFECT that tools have had on the progress of civilization. It has been stated that the progress of peoples can be traced through their development of tools and tool materials. That is quite obvious from historical studies. The application of tools to our modern industrial development, however, is not quite so obvious. What is now happening is the transfer of hand tools to machines — a point I made in a paper published in *Journal of Applied Physics* last year, and from which the following is largely taken.

Consider the anvil, the hammer, shears, punches, knives, saws, chisels, tongs and the like. These came into existence originally as hand tools. For centuries, much of the progress of the civilized world depended on the development and use of these as hand tools.

Our oldest tool material of any great moment is high carbon steel. Carbon tool steel is still used in tremendous quantities in the manufacture of tools for cutting or battering other metals, wood, flesh and all manner of substances. It is used, however, for machine parts in even greater quantities.

Take, for example, lathe chucks. These involve some combination of the tongs and the vise, being a mechanical grip to serve the same purpose as the hand grip. Starting from this simple example, one can visualize in a single machine many combinations such as the grip, the file or its equivalent, the saw, the shear, and the punch, operating simultaneously or in quick succession and producing parts at the rate of a hundred per minute.

The evolution, then, of a tool material is from its use as a tool — and usually in the old days as a hand tool — to a machine part. The same trend is observable in the alloy toolsteels. One of the commonest substitutes for plain carbon toolsteels (and one of the earliest alloy steels to be commercialized) contains about 1% of chromium. It is also used for ball bearings, and the tonnage used for ball bearings today is far greater than that of the same material used for the simple tools.

When high speed steel came into use in the early part of this century, many people thought it would replace carbon steel in tools. It did replace many carbon steel tools, but there are more carbon steel tools made today than there were in the first part of the century. What high speed steel has done is to make possible a greater machine age, and it has appropriated part of the tool industry, but it has not decreased the output of high carbon steels.

Again we see the same phenomenon. High speed steel first came into use as a tool material, and now it has many other uses. It is destined to have still more uses outside of the typical field of metal cutting tools. The same is true of stellite, which is essentially an alloy of cobalt, chromium and tungsten. Stellite first came into commercial use as a tool material, and now it is being used in greater quantities for machine parts, not only for hard surface facing, but also as cast stellite parts, hard in themselves for wear resistance.

The newer tool materials are the cemented carbides, representing a new art. The utilization of powder metallurgy in the production of these materials represents an advanced industry, at the present time well launched the world over. The material handles more like diamond than

like a metal; on the average, in the United States, a pound of it is now divided into 90 pieces before it goes into use. Even so, in the year 1936 upwards of 50 tons of the material was consumed throughout the world.

Even the cemented carbide has already started in the direction of use for machine parts as distinguished from the tools themselves. I have in mind one machine which uses 25,000 cemented carbide wearing points. From among the regular production at that period may be selected one die for drawing steel tubing. That die is in one piece and weighed 5½ lb. The 25,000 pieces (really 25,000 small tools) also weighed 5½ lb.!

Such improved tool materials, when applied to machines, may have a life which compares with formerly used metal parts in the ratio of hundreds to one.

Although the cemented carbide industry is young, it has within a few years changed from use solely as a tool material to application in machine construction. Hence it is undergoing in the course of a few years the type of evolution through which the ordinary carbon toolsteel took thousands of years to pass.

The advantage, of course, is not only in the longer life itself and in the fewer defective parts made before the worn-out fixture is actually replaced. Some of the advantage derives from lessening the attention required for the operation of the machine. If one has to change tools or wearing parts two or three times daily, the machine needs almost constant watching during operation. If the part has to be changed only once in six months, the operator need give little attention to it.

An even more recent entry into the lists is an intermediate material, an alloy of iron, cobalt and tungsten. By substituting iron for the chromium of stellite and changing the cobalt and tungsten content materially, an alloy can be made which is not hard when it is first cast. It can also be forged and rolled, and then it is susceptible to heat treatment. There is no carbon — or at least not enough to produce carbon hardening. After this alloy is forged and rolled, it can be heated to a high temperature, say 2300° F., and cooled fairly rapidly, after which it is relatively soft and machinable. The hardness at that stage is about Rockwell C-45. It can then be reheated to 900 or 1200° F. and the hardness can be brought up to any value desired between C-45 and about C-70 with good cutting properties.

It has a peculiar behavior in machining the austenitic steels. It machines these better than any other tool material. Why that is I do not know. Even this material, new as it is, and used to only a very limited extent for tools at the present time, is already finding use outside the tool field. It is an even newer material than cemented carbide and yet, within two or three years, it is going through the same type of evolution.

From these trends one might be led to believe that the new tool materials would be sure in time to crowd out the old ones — first plain carbon steels, then low alloy steels, finally high speed. This is no more true now than it was in 1900. The cemented carbides will take up a proportion of the growth which is on the way in this country. High speed steel, 15 or 20 years from now, will be used in greater tonnage than it is today. In other words, it will be a bigger industry as the years go by, just as the carbon steel tool industry, or its equivalent, is a greater industry today than it ever was before.

A greater elaboration and refinement in all branches is rather to be expected. Special varieties of the new tool materials have already appeared, one more suitable for steel, one more suitable for cast iron, one more suitable for aluminum alloys, and so on. This is exactly parallel to what we find in toolsteels — see, for instance, James P. Gill's classification in last October's METAL PROGRESS, where 12 distinct groups are listed, each having some special reason for existence, and each group in turn containing several individuals each with its own characteristics.

ZAY JEFFRIES

Metals Handbook

DUE TO THE GREAT INCREASE IN MEMBERSHIP during the past year the supply of the 1936 edition of Metals Handbook has been entirely exhausted.

We regret to announce that there will be an interval of about eight months before the new revised edition is off the press. When the new Handbook is published, each new member who has not received a copy of the 1936 edition will automatically receive a copy of the new edition.

The Handbook Committee and the various sub-committees are working strenuously on the new edition and every effort will be made to speed up the date of its publication.

W. H. EISENMAN

metals used in the Aircraft Industry

Large passenger transports are one eighth alloys of iron, seven eighths alloys of aluminum. Two dozen steels, more or less, comprise the iron alloys, but the principal ones are the weldable chromium-molybdenum X-4130, and the 18-8 stainless steel. Strong aluminum alloy sheet (alclad) and extruded shapes form the bulk with castings and forgings also utilized

THOSE OF US ENGAGED IN AERONAUTICAL RESEARCH are firmly convinced that there is no phase of engineering science which does not, in some manner, find its way into the problems of producing airplanes. This, of course, is particularly true of the modern large transport. The same applies to the number of different materials used; they increase as a direct function of the size and complexity of the aircraft under construction.

There seems to be a popular misbelief that the amount of metal other than aluminum is so slight as to be entirely negligible. Such is very definitely not the case. By way of example, a standard 21-passenger airplane used by practically all of the major airlines in this country and many abroad, contains about 17½% steel in the structural weight of an empty airplane, *sans* engines, propellers, starters, generators, radio equipment, light, instruments, interior furnishings and batteries. In actual weight, this item alone amounts to very nearly 1750 lb. and if the weight of the steel used in the engines, generators, starters, and other auxiliaries be included, the total weight of steel will be found to be considerably in excess of one ton.

It is true, of course, that the alloys of aluminum and alloys of iron will together amount to virtually 100% of the structural weight of the airplane, but it is apparent that serious attention must be given, in any discussion of the metals used in aircraft, to those materials which are not alloys of aluminum.

There are at least two dozen different kinds of steel used in a single modern airplane. Most important of all, as far as tonnage is concerned, are the familiar chromium-molybdenum and stainless steels. The former is used for highly stressed structural parts, the latter where corrosion resistance and high temperature stability are the important requirements. The number of feet of chromium-molybdenum tubing which has gone into the familiar welded steel fuselage is rapidly reaching astronomical proportions. The availability of this alloy steel (S.A.E. X-4130) along with its excellent physical properties, ease of forming and the reliability of the welds made with it, has made it the most important structural steel used in aircraft today. In the monocoque type of fuselage and wing construction, where aluminum alloys are primarily used, the landing gears, engine mounts, and other highly stressed parts where welding is necessary and space is at a premium, are made of Cr-Mo steel tubing, bar stock, and forgings.

By J. Richard Goldstein
Research Engineer
Douglas Aircraft Co.
Santa Monica, Cal.

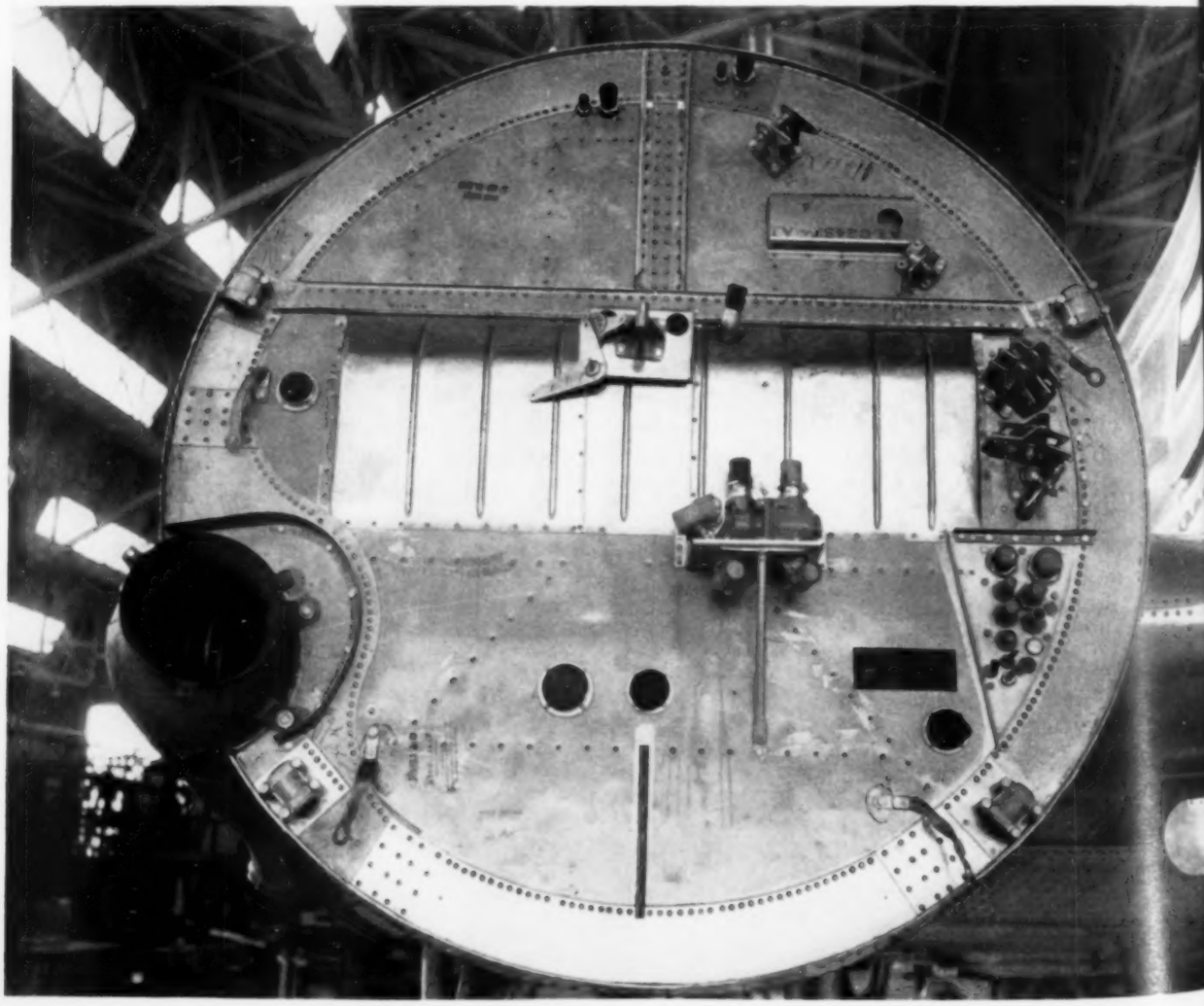
A Paper for the American Society for Metals, Western Metal Congress

At the present time, the largest proportion of stainless steel used is the popular 18-8 chromium-nickel type. Most of it can be found formed into collector rings for the exhaust gases from the engines, for firewalls behind the engines, and for those parts where extreme corrosion resistance is necessary. It has not been widely adopted as a structural material because of the special methods required for its fabrication; methods which are required partly because 18-8 develops maximum physical properties only as a result of mechanical working, and does not respond to heat treatment. However, those who have made a serious attempt to substitute it for the lighter alloys of aluminum, are very enthusiastic about its possibilities in aircraft applications.

(It can be shown that the strength-weight ratios obtainable with the most common structural materials — namely, wood, aluminum alloys, magnesium alloys, and steels — are so nearly equal that most fair-minded authorities will admit that intelligent design with any of them can result in a structure of very nearly the same efficiency. The difference becomes more important when one considers such items as number of units to be built, size, type of service for which the airplane is intended, and expected life.)

Some difficulty has been encountered with the welding of stainless steels where the parts are to be used in the combined presence of vibration and high temperature. The active, corrosion resisting chromium was depleted due to a formation of chromium carbide by a combination of the chromium with the carbon in solution in the steel, often aided and abetted by the carbon in the welding flame. This has been brought under control by a carefully guarded maximum carbon content in the steel, and by the addition of titanium or, more recently, columbium, to the alloy which forms harmless carbides in preference to the chromium. In fast spot welding by electrical resistance, the use of these special measures is unnecessary, since the time at which the material is at welding temperature is so short that the carbides do not have a chance to form. The melted volume in

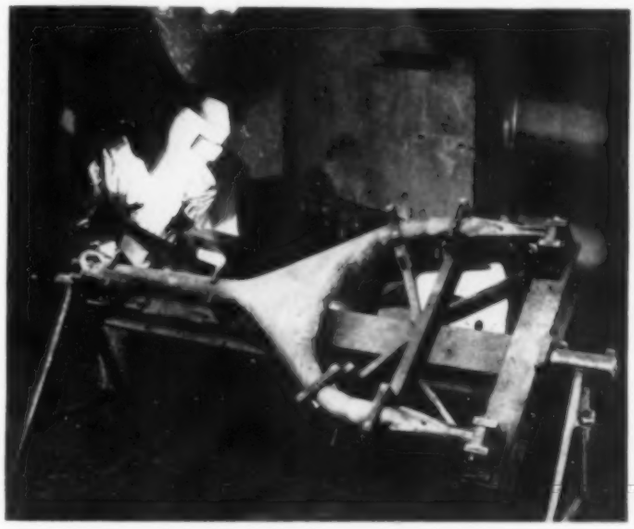
Stainless Steel Firewall in Engine Nascelle for Large Douglas Aircraft. Note boiler at left



this type of weld is virtually surrounded by unmelted material.

A considerable amount of nickel steel goes into aircraft in the form of bolts and nuts and other threaded parts. The excellent threading properties of this material make it highly desirable for certain complicated hydraulic fittings. Other types of steels are used for special applications such as springs, hardened and ground pistons and shafts, ball bearings and snap rings.

Steel castings are not widely used, due to the incongruity in using a material of inherently high strength in an application where the results cannot always be depended upon, necessitating a rather high margin of safety and excessive weight. Important progress has been made recently in this line, however, and there is every indication that their use will become more common.



Yoke for Landing Gear, in Welding Jig, Made of Air Hardening Chromium-Molybdenum Steel, S.A.E. X-4130

More alloys of nickel are likewise being used. Two of them are especially worthy of mention: "Inconel," a nickel-chromium alloy, where high corrosion resistance and strength at both normal and elevated temperatures are advantageous, and "K-monel," a nickel-aluminum-copper alloy, non-magnetic, a good corrosion resistor as well as inherently strong and susceptible of further improvement by heat treatment. The non-magnetic feature of the latter, combined with high strength, allows its use close to a magnetic compass.

Brasses and bronzes are used but to a limited extent. What brass is used is in the form of bars for machining into special parts such as hydraulic fittings. Manganese bronze castings are used in certain applications where the high strength, good corrosion resistance, and ease of casting are paramount. Where pressure tightness is important, gun metal is used.

Most of the magnesium alloys used in aircraft are in the form of castings, which are susceptible to an increase in physical properties by heat treatment, whereas the available wrought alloys are not. The main item in their favor is weight — only two-thirds that of aluminum. The disadvantages are rather poor corrosion resistance in the presence of salt water, and a somewhat over-emphasized fire hazard, especially in machining operations and in thin sections. (With proper care it has been found that this fire hazard can be reduced to a very low minimum.) Corrosion resistance has been improved to the point where the material, protected by a chromate dip, seems to be perfectly satisfactory when exposed to inland air. Even salt air has been satisfactorily resisted after a simple treatment. At the present time, magnesium alloys are generally limited to secondary structural parts and interior appointments. The results of service tests now in progress will decide how much will be used in the future.

Last, but far from least, come the alloys of aluminum. Their widespread use is due in no small measure to the rapid advances, not only in the product, but also in the methods of fabricating and refinement of design. It is the result of an "unvicious" cycle; the initial properties created a large demand which increased the properties and workability, which in turn again increased the use, which bettered the design practice, and so on! The fact remains that the aircraft industry did much to make the demand for alloys of aluminum what it is today, and aluminum has been very important in the development of the modern airplane.

The paramount advantages which contributed to the use of aluminum alloys are the high strength, the low weight, the ease of forming, and the inherent corrosion resistance of pure aluminum. In most large modern aircraft, it is used to the practical exclusion of other materials except where exceptionally high strength and low bulk are considerations, or special wear resistance, high temperature, or

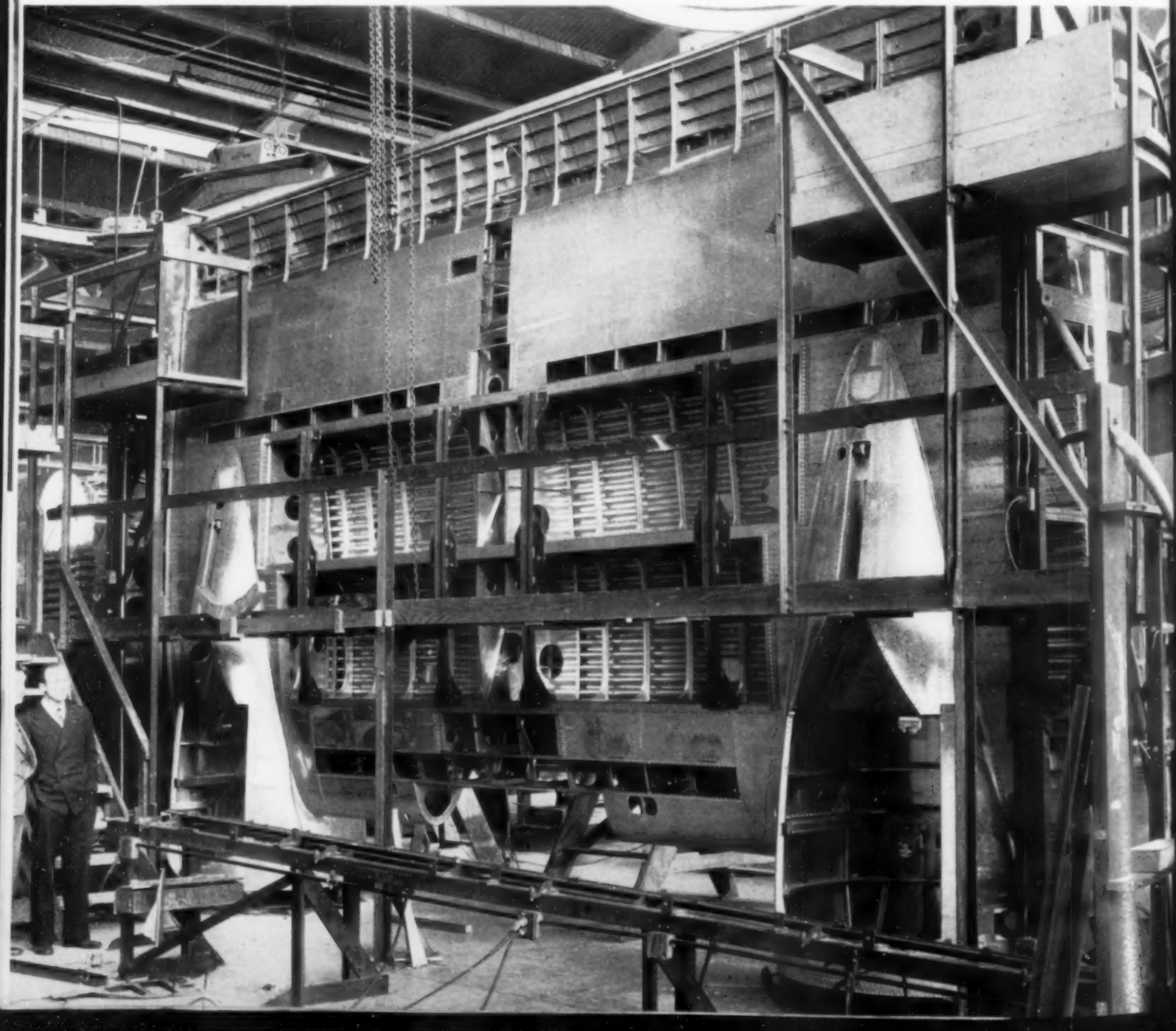
special corrosion resistance requires other materials.

The general adoption of the hydraulic press for forming, together with the advent of the monocoque method of construction, has made sheet stock probably the most important single form of aluminum alloy used in aircraft. The largest use obvious to the layman is in the stressed skin covering of both fuselage and wing. Not so obvious is the quantity of sheet stock in wing ribs, fuselage frames, panels and brackets. Sheets of almost every available composition are used, some for their special working properties, some for their exceptional strength, many for their resistance to fatigue cracking.

Most of the sheet stock is used in a high strength alloy which responds to heat treatment. The heat treatable feature is very important where severe forming operations must be performed on soft stock, but where the finished articles must have a maximum of strength. Here the age hardening properties peculiar to some alloys are very important, for they permit working in a relatively soft state; after the part has been formed, the physical properties gradually and automatically increase to a maximum. This feature is depended upon only for specialized applications; it obviously is not adapted to methods of heterogeneous production.

Extruded shapes of aluminum alloys are extensively used, not only because of the high physical properties obtainable in the material in this form, but also because the exact although intricate shape desired may be had in long lengths at reasonable cost. The physical properties of extruded alloys are just about the same

Wing Intersection of Strong Aluminum Alloys, for a Transport, Partly Completed



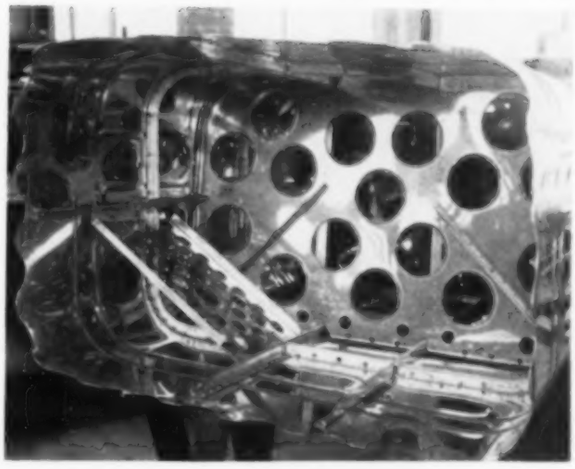
as the properties for the same alloy in sheet form, although the sheets can often be strengthened somewhat by cold rolling. Most of the extruded sections are used as stiffening members in monocoque contruction.

Cast alloys of aluminum are also obtainable in analyses which respond to heat treatment. Sand castings are used primarily for those parts which can be so made more economically (considering weight balanced against cost) by eliminating the large number of machine operations necessary to make them from plate or bar wrought alloys, even though the allowable fiber stress is lower. Sections as thin as $\frac{1}{8}$ in. are easily obtained on small sand castings. Shock and fatigue resistance, as well as ductility, is much less than for the wrought alloys.

Where a sufficient number of parts are involved, or where it is economical by reason of decreased weight and increased reliability, permanent mold castings are often used. The production technique is much the same as that for sand castings. However, the chilling effect of the mold on the molten metal seems to result in a finer structure, and this is believed to account for the increased response to heat treatment, the better corrosion resistance, the lessened susceptibility to fatigue surface cracking, and the increase in physical properties (as compared to sand castings). Wall thicknesses may be reduced to a minimum of $\frac{3}{32}$ in., and tolerances may be held to $\pm$ 0.01 in.

Where there are a large number of small accurate parts required, die casting is used. Aluminum die castings have a relatively low shock resistance, as compared to wrought alloys, but their main attraction lies in the fact that it is possible to cast parts of great complexity, actually inserting other materials in the die, and having the finished part correct to small tolerances, as low as 0.0025 in. Minimum wall thicknesses of 0.030 in. are obtainable. The parts can be produced to an exceptionally smooth finish by careful manufacture of the die, and holes can be cast into the parts which are ready for reaming or tapping. Die costs are rather high, but this method offers an inexpensive means for mass production.

Aluminum alloy forgings are used where the production quantities justify the increased cost of the die and decreased weight of the parts. Not only are the allowable strengths higher than for castings — actually they are equal to the best wrought alloys — but they have a more uniform and dependable structure. Forgings of aluminum alloys are used for such highly stressed and vital parts as wing fittings and landing gear attachment fittings. The strength-weight ratio of the newer aluminum alloy forgings compares very favorably with the best steel structures available, and aluminum alloy forgings will probably be favored where the cost of dies is not too important, or where space limitations do not prohibit the necessary bulk.



Gasoline Tank Under Construction of Aluminum Alloy Sheet. Near end removed to show inner stiffening bulkheads, surge dampeners, and bracing

One of the most important developments in the manufacture of aluminum alloys in the recent years has been the so-called "alclad" method of protecting the high strength alloys from corrosion. This process consists of the application of a thin layer of purest aluminum to each side of the sheet (the only form, other than wire, in which this feature is now available). High strength alloys are inherently corrodible, and "alclad" has eliminated one of the few stumbling blocks in the way of their more widespread use. However, it results in a strength drop of approximately 10%, equal to the thickness of the aluminum coating.

There can be no doubt that the advent of the all-metal airplane marked a very definite upward turning point in aviation. The modern airplane of today can fly farther, higher, faster, and safer than could its predecessor, and can continue to do so for more years than it takes for the design to become obsolete. The more widespread use of metal in aircraft construction has had much to do with this progress.

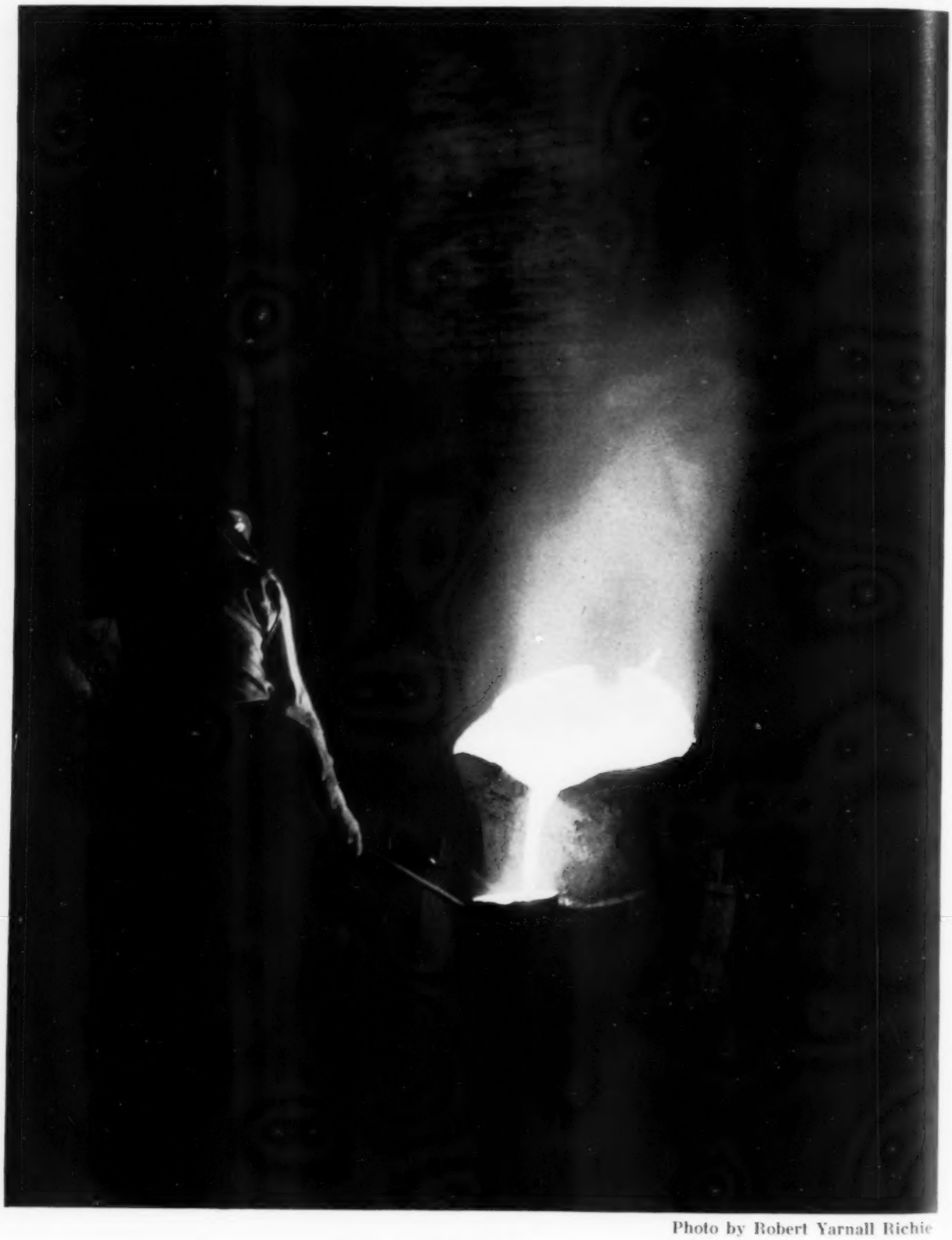


Photo by Robert Yarnall Richie

A Ladle of Iron

Foundrymen Discuss present-day problems

A gathering of active workers talked "shop" in 22 formal sessions and innumerable informal meetings. The formal sessions were themselves informal to the extent that they were free-for-all discussions, incited by provocative chairmen, rather than prepared papers, endured by some listeners. Melting practice and heat treatment operations were important topics of the two-day meeting

YOUR REPORTER ATTENDED HIS FIRST REGIONAL conference of the American Foundrymen's Association at Milwaukee in February, and what he saw and heard has kept him thinking about it ever since. The $3.00 registration fee came as somewhat of a shock but too late to do much about it, and maybe it would be legitimate "expense" anyway, so he joined the group of 292 participants. Later it developed that included were two excellent lunches, an interesting discourse on intercollegiate athletics by Harry Stuhldreher of the "Four Horsemen," and a side splitting talk by Capt. Humbugo Forcetti of the Italian Aviation Corps. That must have accounted for at least $2.25 worth, and a tough casting job may be solved by accidentally meeting an acquaintance. If that works, there will be the entire $3.00 and the "expense" angle can be forgotten!

The technical program was divided into five main sessions, each presided over by a carefully selected discussion leader whose experience was broad and who knew the problems and talked the language of the subject assigned. Much of the success of this meeting can be directly credited to these gentlemen. There was never a dull moment and it appeared that at least half of those in attendance took part in some way.

The general sessions opened with an illustrated talk on "Castings in Relation to Other Departments" by A. F. Pfeiffer of the Allis Chalmers Mfg. Co. An interesting use of a model casting was described. If a large and intricate casting is required, a small model is first designed, poured, and put through all the departments which will handle the full sized casting. This is not expensive, relatively, and experience has shown that the important problems are brought to light and then can be solved in advance. The cooperation needed between the engineering department, the pattern shop, the foundry, and the machine shop, was brought home by apt illustrations. The larger foundry must also consider the plant facilities very carefully.

The question of shrinkage was discussed in connection with the design of the casting and the core work needed. It cannot always be adequately predicted on the basis of linear or volume changes which occur upon solidification. Cleaning large castings with high pressure water was shown to be both economical and "labor saving," in that a very onerous job, and one which has serious health hazards, is done in a really humane way.

One of the most interesting features was a discussion of the repercussions among groups with mixed and overlapping responsi-

By S. L. Hoyt
Milwaukee, Wis.

bilities due to the finding of an off quality casting. This calls for an open and frank consideration by all concerned. Possibly the casting can be used in spite of the defects found and in most cases valuable information is obtained which can be used to instruct all of the personnel.

Apprentice training is being handled in a very enlightened manner in Wisconsin, due in no small measure to the wise legislation which forms the framework on which the system is built. Here is a plan which enables many hundreds of high school graduates to learn a fine trade and by methods which must make them feel they have a stake in the company and the community.

Effect of Moisture on Iron

The two sessions of metallurgical interest were on cupola practice and malleable iron. The former was presided over by George Long of Pickands, Mather & Co. with R. S. MacPherran of Allis Chalmers acting as secretary. Metallurgists who wonder why gray iron goes wrong at times learned the details of cupola construction and cupola operation that must be controlled to avoid trouble. The charge ought not be greater than about one ton, to avoid having too great a thickness of coke between charges. The amount of water in the coke should be determined and a correction made for its weight, to secure the actual weight of carbon charged. The simple pressure gage for air is no longer considered to be adequate and Mr. Long advocated the use of volume control with daily corrections for water content. Another solution of this problem is obtained by use of a special blower that delivers a uniform weight of air when the power input is held uniform.

We also learned that many details of design and construction of the cupola are most important to efficient operation. The "continuous" tuyere was held to be inadequate, and the square type preferred to the conventional circular type. The tuyere must not only deliver the correct weight of air into the center of the furnace but must direct it to the bed of coke for uniform combustion. Failure to charge the cupola properly and improper design of the tuyeres can cause oxidation of the iron by impingement of the blast on the unprotected metal. The hearth should be large enough to hold two charges and allow the metal to mix.

Ordinarily "oxidized iron" is recognized from "stars" that shoot off the metal as it is tapped; the drop in manganese and silicon is also a sign. An analysis of the metal for gas was recommended as a more accurate determination of the condition. This is very much an unexplored field, but we do know that a sample of poor iron contained a large amount of oxygen as iron oxide as compared to a good iron which contained practically none. This does not appear to be a very serious cause of spoiled castings, for it was stated that 90% of the rejects were caused by wet refractories and the poor metal from the first heat.

The temperature of the iron is important, for "molten iron cleans itself if hot enough" but cold metal does not. One point that impressed this reporter was that water, in the air or in the coke, was held to be significant only in so far as the weights were affected, but not for any harmful effect it might have *per se*.

L. J. Wise of the Chicago Malleable Casting Co. presided over the sessions on malleable iron. In this country, 73.7% is melted with pulverized coal, 3.3% with fuel oil, 8.2% is melted in the cupola, 1.5% in the openhearth, and 15% by the duplex process. The relative advantages and economies of these methods were discussed at some length, the consensus being that good malleable is made in the electric furnace but the product of the cupola is not uniform. Most of the discussion related to the commercial features of furnaces and melting practice.

As to annealing, 45.2% of the castings are annealed in pulverized coal furnaces, 18% in oil fired furnaces, 13.5% in hand fired furnaces, and 3.2% in electric furnaces. The work being done by the Battelle Memorial Institute on the use of a combustion unit for powdered coal is being watched with great interest by the industry. It is reported that good combustion is secured and no trouble is had with the ash.

A new porous type of refractory brick permits a reduction in time from 160 hr. to 96 hr. The use of 4½ in. of insulating brick was advocated to give the correct cooling rate for malleable. Still better control is secured with electric heat, and shorter time cycles are possible with controlled atmospheres.

Aside from the necessity of securing the correct annealing temperature of 1650° F., a problem is introduced with fuel fired furnaces of cooling rapidly and checking the temperature at 1300° F. and holding it constant until sufficient pearlite is decomposed to meet the metallurgical requirements.

The steel session on melting was presided over by W. Harvey Payne of the Pittsburgh Lectromelt Furnace Corp. In line with the accepted method of presentation there was no attempt to give an orderly or comprehensive treatment of melting practice. This was a gathering of practitioners and the points were discussed as they came to mind. Perhaps the principal points affecting the production of good steel that were considered were *(a)* the necessity of eliminating the metalloids, followed by a refining period during which the residual carbon reacted with the oxides of the bath and *(b)* providing a more powerful deoxidation with a reducing slag before any of the final deoxidizers are added.

The final stage should be accomplished as speedily as possible and the heat should be tapped soon after the silicon addition. Two evils to guard against are the retention of initial silicon, and holding the heat for too long a time under the reducing slag. The addition of aluminum to a bath that has not been properly prepared for it (oxidized and gassy) is quite futile. One case was recited of the recovery of an over-reduced heat by pouring it back into the (electric) furnace, and taking it again through the oxidizing period to eliminate the silicon.

One point which your reporter missed in this discussion was the effect of temperature. Just how the other elements of control are to be made effective without temperature control was not made clear, though considerable attention was paid to slag control.

Gases came in for consideration too. Basic heats generally give less trouble in eliminating silicon, but the color of the slag is not as secure an index of the over-reduced condition. A case was cited of a metallurgist who changed his furnace to acid but found that his castings contained pinholes and he went back to a basic lining. His trouble with the acid lining was due to excess silicon, which was easily eliminated and caused him relatively little trouble with the basic slag. Heats which cannot be killed by aluminum additions probably have not lost enough silicon during the refining period.

Special Cast Irons

Two sessions of interest to the general metallurgist were on electric cast iron and treatment. The former was held under the guidance of Garnet P. Phillips, Metallurgist of the International Harvester Co. There seems to be no particular superiority for either the direct or indirect arc furnace for most purposes, though both, when favorably used in continuous operation, cost ½¢ per pound more than the cupola. On the other hand the electric furnace is much more flexible and is capable of producing a superior quality of iron castings. It is particularly suited to melting low carbon and alloy cast irons and for heats that require a high temperature; it is also possible to "work" cast iron heats in the electric furnace the same as steel heats.

Considerable discussion was had on the use of borings in the electric furnace. Apparently they remain a problem and at the most can be used for only part of a charge. One effect is that of increasing the shrinkage, presumably on account of excessive oxidation. This effect is apparent even though the borings are briquetted. (An interesting case was cited by Mr. MacPherran of spontaneous ignition of a pile of borings which kindled some boards alongside.) Some felt that borings raised the tensile strength of the iron and lowered the deflection, but this opinion was not shared by others among the audience.

Advantages of Electric Furnace

It is now quite generally admitted that properly made electric iron has better properties than cupola iron of the same conventional analysis. The structure and metallurgical characteristics, such as depth of chill, likewise differ. A specific case of melting "Ni-resist" cast iron was discussed. This contains 15 to 20% Ni, 1.3% Si, and 2.7 to 3.2% C. The carbon must be held to less than 3.3% or an excess separates and the casting must be scrapped. A hardness of 170 Brinell was recommended for machinability. Foundry practice also has to be changed to take care of the higher shrinkage.

Impact tests for cast iron came in for attention. While such a test, if reliable, would be of great value, it appears that no satisfactory test is now available.

A session on cast iron heat treatment was presided over by O. T. Muehlemeyer, President, Metal Treating Institute, Rockford, Ill. The three major objects of heat treating cast iron are to improve machinability, to make it more permanent in dimension and structure, and to give it certain desired properties. If the casting is too hard in the as-cast state, it may contain so much combined carbon that it cannot be

satisfactorily machined. In this case it may be softened by annealing at 1450° F. or above. Ordinarily this will break up the combined carbon but some irons, for obscure reasons, fail to respond or will require an excessively high temperature or long time. Of course the introduction of tools made of cemented carbide has materially altered our ideas of machinability of cast iron. On the other hand some irons may be too soft and they can be improved by air cooling from 1450° F. Some plants make it a practice to quench important castings in oil from 1550° F. and draw at 400° F. or above to secure the hardness desired.

The time required for annealing appears to depend on the condition of the iron, which in turn depends on the design and operation of the cupola, and tuyeres, and air control. Presumably the electric iron would be better for heat treating purposes than cupola iron. The general formula of one hour per inch of cross-section is used for estimating the time of holding at heat, the same as for steel. However, with cast iron a longer time at a lower temperature is better practice than the use of shorter times at higher temperatures. The effects of elements not commonly determined analytically were discussed in this connection.

Stress relief came in for considerable attention. While the practice has been well standardized and is effective in producing permanent dimensions, the process is not thoroughly understood as yet. Temperatures used vary from 600 to 1250° F. with 950 to 1000° F. being common. Larger castings cannot be handled safely at temperatures above 950° F. though this temperature is adequate even for turbine and cylinder castings which must retain dimensional accuracy throughout long life. The "twilight zone" between the full anneal and the stress relief anneal received considerable attention. It appeared that temperatures such as 1100 to 1300° F. might be expected to act quickly and effectively to relieve stresses but there would be greater hazards from cracking the castings and some softening would also occur. The full heat treatment of cast iron has been a recent, though important, development.

Hydrogen Attack on Steel

Abstract from The Metallurgist, Supplement to The Engineer, February 1938

HEAT TREATMENT OF STEEL IN CONTROLLED ATMOSphere — especially at hardening temperatures — has resurrected the question of hydrogen attack on steel. Bright steel surfaces are not enough; the ideal atmosphere must also have no influence on the carbon or other alloying elements contained. Other aspects of the hydrogen problem are found in the embrittlement of hard steel by acid pickling, the blistering of soft sheet steel under certain circumstances, and the failure of pressure vessels used in ammonia synthesis.

Early experience in high pressure hydrogenation plant, such as that used for ammonia synthesis under pressures of 100 to 1000 atmospheres at 800 to 1100° F., and in the hydrogenation of coal for the synthesizing of gasoline at pressures up to 700 atmospheres at 850 to 1000° F. revealed the serious attack on carbon steels under these conditions. The attack consists of decarburization, associated with cracking, which, even on a microscopic scale, leads to marked deterioration of strength and ductility, and ultimately to failure.

Although certain alloy steels have proved to be far more resistant to hydrogen attack than carbon steels, experimental investigation of the behavior of carbon steels is still necessary, especially with a view to the elucidation of the mechanism of hydrogen attack.

Hydrogen attack at high temperatures and pressures is regarded as essentially different from low pressure decarburization such as would arise during heat treatment, the first process being characterized by the production of methane, and the second by the production of carbon monoxide.

In high pressure hydrogen attack the methane formed in the decarburization accumulates at the place of reaction on account of its slow rate of diffusion, thus giving rise to high stresses which ultimately lead to cracking. Initially, very little carbon is removed, and decarburization is not detectable by analytical or microscopical methods until some damage to properties has already taken place. This damage is observable on the impact test; for

(Continued on page 402)

Silicon Impregnation of iron and steel

If articles made of common steel, low in sulphur, are heated in rotary or pot type of furnace in contact with silicon carbide and chlorine at 1800° F. a case of 14% silicon-iron is formed at the rate of about 0.015 in. per hr., closely adherent to the core, and exceedingly resistant to oxidation, strong acids and mild abrasion

THE IMPREGNATION OR CEMENTATION OF FERROUS metals with other elements has been practiced for many years. While iron has been impregnated with many different elements experimentally, carbon was the one earliest and most widely used. More recently, articles have been impregnated with nitrogen and with aluminum on a commercial scale. The principal object of carbon and nitrogen cementation is to impart hardness to the surface of ferrous metals, and that of aluminum to render the surface more resistant to scaling at high temperatures.

A cementation element that would make the surface of iron more "noble" would by definition increase its resistance to corrosion.

Silicon is the most plentiful and least expensive iron-ennobling element known. The resistance to corrosion of alloys of iron containing over 10% silicon has been amply proved by years of actual service experience as well as by numerous laboratory tests. Because of their high price, brittleness, and limited fabricating qualities, the widespread use of such high silicon-iron alloys has been quite restricted.

Since ferrous metals are attacked by corrosive reagents on their surfaces, a high silicon content case on a common steel core should combine the desirable corrosion resisting properties of solid silicon alloys with the strength, ductility, and other desirable properties of the steel core. Such an article would be largely made up of cheap common steel which could be fabricated economically in any way necessary, and then the silicon alloy case be added as the last operation. If such a silicon cased article could be produced cheaply, it should find many applications.

Greiner, Stoughton and Marsh, in "Alloys of Iron and Silicon," pages 315 to 318, give a review of the literature on silicon impregnation. They say, "Interest in the possibilities of relatively high silicon cases on low silicon cores has run high from time to time. Theoretically, such a case, assuming the silicon content to be sufficiently high, should enable the production of corrosion resistant non-brittle apparatus." After describing various silicon impregnation methods, they conclude with the statement that "It is to be seen that the cementation of iron by silicon has attracted considerable attention and that various investigators have shown conclusively that the operation is possible, but judging by the nature of the silicon bearing cases produced thus far, its usefulness is still somewhat questionable."

Cementation of iron with silicon has been accomplished previously by packing in silicon and ferrosilicon and heating to very high temperatures in rigorous reducing atmospheres. A thin case

By Harry K. Ihrig
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has been produced after long exposure to these high temperatures. Volatile chlorides also have been added to the ferrosilicon to speed up the process. These volatile chlorides either volatilize out of the retort or attack the articles to be treated before they get to the reacting temperatures.

Silicon Carbide and Chlorine Used

A new method, whose manufacturing and licensing rights under United States and Canadian patents and applications are controlled by Globe Steel Tubes Co. and the author, has been developed which produces a high silicon case in a short time without the use of inert or reducing gases during the actual cementation. As now practiced commercially, it subjects iron or steel articles to the action of silicon carbide and chlorine at temperatures of 1700 to 1850° F. Instead of silicon carbide there may be used ferrosilicon or mixtures of the two. Parts may be processed in a rotary or pot type furnace, and the chlorine is added when the parts are at treating temperature. Ordinary carburizing equipment may be used with only slight modifications.

The case may be made almost any desired depth from 0.005 to 0.100 in. The usual case of about 0.025 to 0.030 in. is produced on low carbon steel in two hours. It is possible for some purposes to effect impregnation throughout the entire section of the article.

It would be expected that introducing chlorine into a metallic retort at high temperatures would cause the immediate failure of the retort from the reaction of the gas on the metal. In the presence of silicon carbide or ferrosilicon this does not occur, probably because the reaction rate on the carbide is faster than that on the metal. By introducing chlorine gas at the impregnation temperature, there is also no attack on the articles to be treated. This would occur if the chlorine was introduced originally, or if volatile chlorides were mixed with the silicon carbide before the charge had come up to the reaction temperature. By using chlorine gas, introduced at the treating temperature, it is easy to regulate accurately the amount necessary for the proper thickness of the case.

The exact mechanism of this reaction is not known. At temperatures up to 1850° F. it appears essential that the carbide be in contact with the article to be treated. It is believed that the chlorine liberates the silicon from the silicon carbide in the nascent form, whereupon it diffuses immediately into the articles to be treated.

Forged, rolled, or cast low carbon steel with as low a sulphur content as possible is particularly suited for the operation. Higher carbon, low sulphur steels can be treated satisfactorily but are impregnated more slowly than those of low carbon content; for example, S.A.E. 1045 steel requires about twice the time at temperature for a given thickness of case that S.A.E. 1015 requires. The silicon case on high sulphur, free machining steels may be penetrated when exposed to corrosive conditions, with consequent cracking and spalling of the case due to attack of the underlying core. This localized attack is probably caused by an intergranular silicon sulphide constituent which is not resistant.

White and malleable irons can be treated, but because of their high sulphur content, the resulting cases are, as a rule, not so corrosion or wear resistant as those produced on low sulphur steel. Gray cast irons, because of their high sulphur content and because they swell badly at treating temperatures, do not give a satisfactory case for many purposes.

As a rule, alloy irons and steels, particularly those containing chromium, do not appear to treat as well as plain low carbon steels.

Usually no special preparation of parts to be impregnated is necessary. The decarburized layer often found on forgings does not have any effect. Sand imbedded in castings must be eliminated by pickling or sand blasting. Ordinary light mill scale does not have to be removed, but heavy annealing scale should be. Because the processing temperature is above the critical point of irons and steels, it is advisable that all strains be removed before treatment; otherwise, they will be removed during the processing and may cause distortion.

Analysis and Structure of the Case

A photomicrograph of a case produced by the above process is reproduced on page 369. Analyses of 0.010-in. cuts are shown to scale at the side. The silicon content is constant (within less than 0.5%) for the first 0.040 in. of the case and then falls off gradually for an additional 0.020 or 0.025 in. This uniformity of silicon content in the outer layers is in marked contrast to the result of other cementation cases, and the parts may be ground to a considerable depth without destroying the best portions of the case.

Thousands of automotive water pump shafts have been fabricated from over-size bar stock without any machining except for the keyways, and after silicon impregnation they are ground to accurate size in a centerless grinder.

Another peculiarity of the silicon case is that carbon from the outer portions of the article is pushed forward by the silicon and is concentrated underneath the silicon case.

A slight swell occurs during the treatment of steel parts. This varies with the type of metal or alloy treated. Parts actually lose in weight during treatment. The following table illustrates the changes in dimensions and weight on a 1-in. bar made from S.A.E. 1020 steel, as determined before and after the silicon treatment.

	Before	After
Weight	602 g.	571.4 g.
Diameter	1.000 in.	1.003 in.
Length	5.985 in.	5.989 in.

Because parts are not quenched after treatment, very little distortion occurs. Where the type of part permits, it may be straightened cold a few thousandths of an inch, or considerably more if heated to about 1200° F.

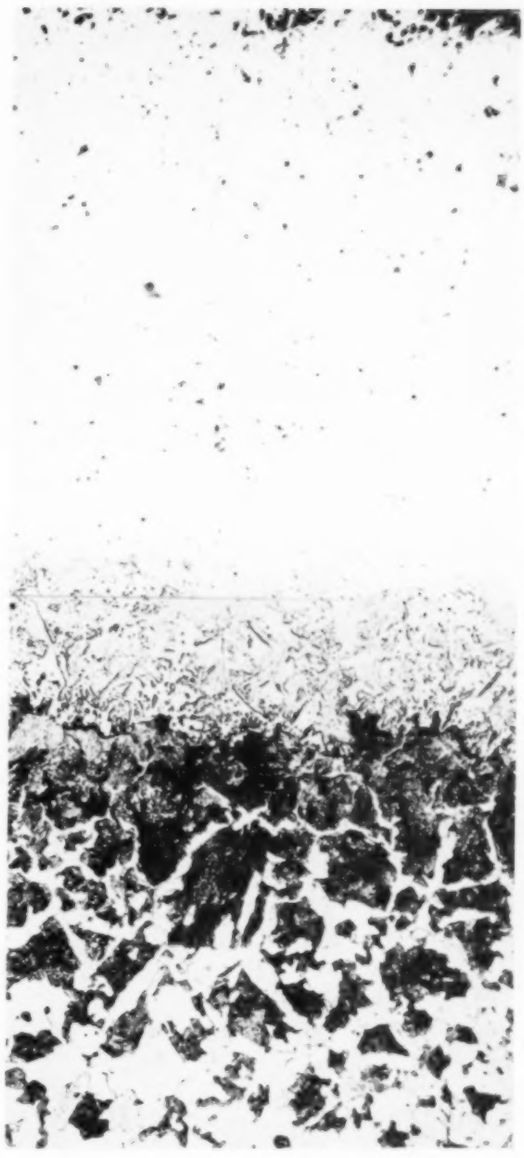
Treated articles show a case hardness of Rockwell B-80 to B-85. Although not file hard, parts cannot be machined or cut with an ordinary hacksaw.

Standard tensile test pieces cut from the same bar of S.A.E. 1015 steel show the following results before and after impregnation with silicon producing a 0.033-in. case:

	Untreated	Treated
Elastic limit	37,750 psi.	37,900 psi.
Ultimate strength	60,550 psi.	51,400 psi.
Elongation in 2 in.	38.5%	19.5%
Case cracked at		41,600 psi.

The case does not crack until the steel is pulled beyond the elastic limit of the core. After the case cracks, the cross-section is reduced and thus the ultimate strength is lowered. The ductility of the case is not as high as that of the core, but treated tubes are ductile enough to be rolled into headers by special methods. The case will not spall off under vigorous hammering. Sharp corners should be rounded off to provide support for the case.

The impregnation with silicon destroys the effects of all previous hardening, and the case cannot be changed by any known heat treat-

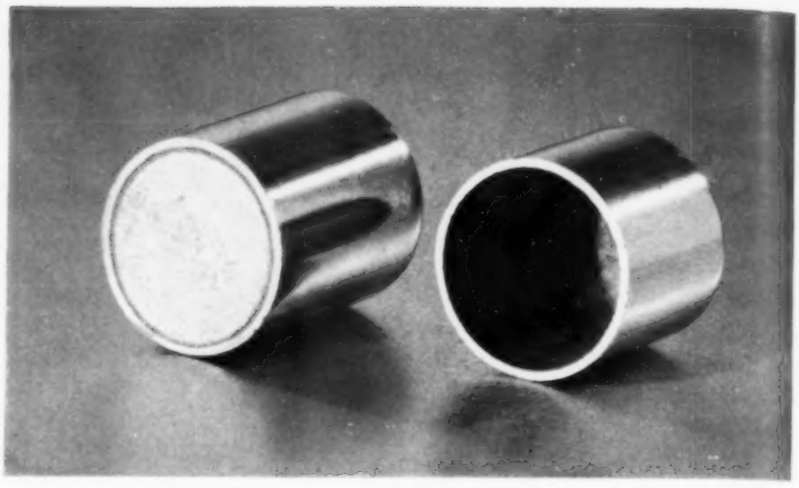


Silicon Impregnated Case (100 ×) Is Somewhat Porous but Securely Alloyed to Core. Carbon in original surface layer of the steel is pushed inward and concentrated at edge of unaffected core. Note analyses of successive 0.010-in. layers

ment; however, the core may be subsequently heat treated to give any properties possible with the particular type of base metal used.

Thermal conductivity of high silicon irons is high, so silicon impregnated articles have about the same heat coefficient as mild steels, and higher than stainless.

The silicon case is magnetic. It shows almost no spark on grinding.



A Short Bar Received a Silicon Case; It Was Then Cut in Two, One Surface Lightly Etched and the Other Boiled in Dilute Nitric Acid, Leaving Behind Only the Corrosion Resistant Shell

Corrosion Resistance

Silicon impregnated articles are resistant to nitric, sulphuric, and hydrochloric acids with a decreasing resistance in the order named. The view at the right shows a treated bar which has been cut in two. One half has been boiled in dilute nitric acid until the entire core dissolved, leaving only a cup formed of the case. The other half has been etched lightly to show the case.

In 10% boiling sulphuric acid, a ½x2-in. round after treatment showed the following losses in weight:

1st 24 hours, 3.1% loss
2nd 24 hours, 0.5% loss
3rd 24 hours, 0.3% loss
4th 24 hours, 0.4% loss
5th 24 hours, 0.4% loss
6th 24 hours, 0.2% loss
7th 24 hours, 0.7% loss
8th 24 hours, 0.7% loss
9th 24 hours, 0.7% loss
10th 24 hours, 0.3% loss

Attack in the first 24 hr. is relatively large, but after that it greatly decreases. This is characteristic of high silicon alloys. An equal piece of common steel under these same conditions is entirely dissolved in about 18 hr. and 18-8 stainless steel in 21 to 30 hr.

The halftones on the next page show two malleable iron elbows that were installed in a steam line over a hydrochloric acid pickle tub. The one on the left had been silicon treated while the one on the right was galvanized. The galvanized elbow failed in less than two weeks, but the silicon impregnated one after five months' service in the same position is still without serious attack.

A treated pump cylinder liner has been in operation on hot naphthenic acid in an oil refinery for the past nine months. Stainless steel and nickel-copper alloys fail quickly under the same corrosive conditions. Treated sucker rod couplings have outlasted various alloy couplings in corrosive oil wells.

Very little electrolytic effect is noticed where silicon cased articles are in contact with other metals; possibly the silica film electrically insulates the case.

Silicon cased articles are not recommended for use in certain boiling acids or in some other violent reagents, because after the case is perforated the core is rapidly attacked. A solid alloy with the same resistance as the silicon case is preferable, for it would still have much of its life left after the removal of an amount equal to the thickness of the case.

The object of silicon impregnation is to produce an article cheaply that is resistant to corrosion. Because the alloy is only in the surface layers which are exposed to the corrosion, the core or major portion of the piece is inexpensive common steel. Parts can also be fabricated from common steel more economically than from most corrosion resistant alloys. As the last operation, they are given the silicon impregnation, which renders them resistant to corrosion. Since corrosion resistance is an economic problem, silicon cased articles seem to be the logical solution for many such problems.

Malleable Iron Elbows From Pipe Line Above Hydrochloric Acid Pickle Tub. One, unprotected, failed in less than two weeks; the other, silicon impregnated, was hardly attacked in nine months

The silicon case is resistant to scaling up to 1800° F. At this temperature excessive grain growth occurs in the common steel core and the case tends to crack, but at temperatures of 1200 to 1600° F. long life has been obtained. A life test made by an instrument company on thermocouple protection tubes cycled at 500° and 1650° F. showed no scaling.

Wear Resistance

While the silicon case is not "hard" to hardness testers using the penetration principle, it cannot be machined nor cut by ordinary methods. Under conditions of frictional wear, such as those to which shafts and cylinder liners are subjected, the case has stood up well. The coefficient of friction is low and the surface is non-galling. Where conditions of corrosion and wear exist together, the silicon case is especially effective.

The case absorbs a small but appreciable amount of oil, which materially increases its wear resistance. The part after treatment and finish grinding, is heated to 250 to 300° F. in a heavy oil. Some of this oil is absorbed and thus the treated part functions as a self-lubricated bearing. This property of absorbing oil is especially effective where outside lubrication is impossible. The table on page 372 gives the results of some Amsler wear tests on silicon impregnated test pieces in comparison with carburized ones. The effect of the oil absorption can plainly be seen. While the carburized case was much harder, it did not wear as well.

Over 10,000 water pump shafts treated by this process have been in use for about two years in heavy-duty internal combustion engines. These engines often operate under heavy load and with corrosive waters. The silicon impregnated shafts replaced alloy shafts impregnated with another element. No shaft ever has been returned because of either corrosion or wear.

An engine test was recently made in the laboratories of an automotive manufacturer on treated cylinder liners after 500 cycles, each as follows:

2 minutes at 300 to 400 r.p.m. idling;
2 minutes at 2500 r.p.m. under full load of 85 hp.;
3 minutes stopped.

Measurements then showed the treated liner to have worn 0.0008 in. while an alloy iron liner under the same conditions wore 0.0015 in.

Field tests on treated slush pump liners in oil field use and on cylinders in foundry air hammer agitators have shown marked superiority in wear resistance compared to cast iron and alloy liners.

The silicon case is not recommended for high velocity abrasion, such as found in sand blasting.

Automotive parts, such as water pump shafts, rocker arms, cylinder liners and valve guides, have been treated and have shown excellent results in service tests. Valves, fittings, and other parts for the chemical, paper, and oil

industries which are subjected to corrosive conditions can be advantageously treated. Forgings, steel and malleable iron castings are rendered corrosion, heat, and wear resistant after treatment. Thermocouple and thermometer protection tubes are standing up well in actual service. Nails, screws, bolts, and nuts also have been treated to withstand severe conditions of use. Tubing used under conditions of high temperature or in corrosive reagents offers a very good field for the silicon impregnation process.

In general, any type of ferrous metal part that is subjected to corrosion, heat, or wear, offers an opportunity for silicon impregnation. Careful testing, however, is essential before large scale production is started on any particular part, to determine whether or not the process is applicable. Since the process is a rapid and cheap one, no doubt additional applications will be found.

Members of the laboratory staff of the Globe Steel Tubes Co. contributed materially in making this work possible. W. J. Resiner is responsible for the many microscopic examinations and photomicrographs of treated articles. Torris Torrison is responsible for supervising the experimental and commercial plant runs. G. Duemling made many of the analyses and tests of the treated samples and also the corrosion tests. S. J. Boehringer, L. R. Miller, and G. W. Thompson assisted in the making of the various runs and also in performing the analyses of the silicon impregnated articles.

Amsler Wear Tests on Treated S.A.E. 1015 Steel

Specimens *(a)*	Rockwell Hardness	Load	Revolutions	Wear *(b)*	Remarks
10% Slippage and $\frac{1}{16}$ in. Side Motion					
C vs. C	C-61	100 kg.	200,000	0.005 in.	Corners chipped
Si vs. Si	C-5	100 kg.	200,000	0.001 in.	No chipping
Si-oil vs. Si-oil	C-5	100 kg.	1,000,000	0.001 in.	No chipping
10% Slippage, $\frac{1}{16}$ in. Side Motion and $\frac{1}{32}$ in. Bump					
Si-oil vs. Si-oil	C-5	50 kg.	100,000	0.000 in.	No chipping
C vs. C	C-61	50 kg.	100,000	0.001 in.	Chipping *(c)*

Notes: *(a)* C means carburized; Si means silicon impregnated, not boiled in oil; Si-oil means silicon impregnated, boiled in oil, wiped dry.

(b) Loss in diameter.

(c) Started at 20,000 revolutions.

Tubing for Oil Heaters

By Ralph L. Wilson

Extracts from paper for Western Metal Congress, March, 1938

The higher temperatures employed in cracking petroleum, the use of high temperatures and pressures in thermal polymerization of hydrocarbon gases, and the refining of the more corrosive crude oils have been responsible for the evolution of a number of new alloy steels for process coil tubing in oil heating furnaces.

The steels being offered to meet these new requirements have been evolved from the familiar compositions previously employed in similar applications. They all contain chromium along with various other alloying elements that have been added to secure special properties. The tendency is toward higher chromium content as the operating temperatures and the severity of corrosion increase.

In a discussion or listing of the newer alloy steels it is always necessary to distinguish between the steels that have actually been used in equipment or have been tested under commercial operating conditions, and those compositions that seem applicable to certain kinds of service on the basis of laboratory tests or the similarity of the steels to other analyses for which satisfactory service records are available.

Among the steels introduced within the last few years, the following may be considered as having been proven either in commercial service or after sufficient plant testing.

Carbon steel with 0.50% molybdenum and 1.50% silicon; to replace plain carbon steel for better strength and heat resistance up to 1100° F.

2.25% chromium and 1.00% molybdenum; for good strength up to 1100 to 1200° F., where corrosion and oxidation are not severe.

5% chromium with 0.50% molybdenum and 1.50% silicon; combines excellent oxidation resistance and good resistance to hot oil corrosion.

5% chromium with 0.50% molybdenum and some titanium; a non-hardening steel suitable for field welding; possesses better oxidation resistance than the standard 5% chromium-molybdenum steel.

9% chromium with 1.15% molybdenum; semi-stainless steel especially good for corrosion resistance; also shows good creep strength.

12% chromium with 3% tungsten; good strength, corrosion and oxidation resistance.

(Continued on page 416)

Hardenability, as It affects heat treated parts

Several methods have recently been proposed for measuring quantitatively the susceptibility of a steel to be hardened when quenched. The author favors an exploration of the variation in Rockwell hardness, edge to center, and points out that appearance of fracture or center hardness may lead to false conclusions

AT THE OUTSET IT IS IMPORTANT TO DISTINguish between hardenability and the potential maximum hardness. For example, comparing a 0.70% carbon steel with a 0.35% carbon steel, the former may when fully hardened attain a hardness of Rockwell C-65, compared with only Rockwell C-57 for the latter, but the two steels may have the same *hardenability*, that is they may require the same speed of quenching to bring about their respective full hardnesses.

If a steel requires a *rapid* quench to harden it, it is said to have low hardenability, whereas with steel of higher hardenability the quench need not be so drastic. A plain carbon steel, for example in ¾-in. round, must be quenched in water in order to harden it and is said to have low hardenability, whereas a steel with sufficient alloy, in the same ¾-in. size, will harden not only in a water quench but also in a milder oil quench, and is said to have higher hardenability. Differences in hardenability may also become manifest even when the quenching conditions are alike, since a steel of greater hardenability will harden to a greater depth.

The concept of hardenability is in reality quite old, even though it had never been studied very precisely until recently. The early use of manganese in plain carbon toolsteels to secure greater or less "depths of hardening" has its modern counterpart in the many alloys used today for controlling hardenability. McQuaid and Ehn reported in 1922 the formation of "soft spots" on quenched carburized steels. This condition was corrected by a larger grain size. Thus, control of hardenability by grain size supplements the methods of controlling it by alloy content.

Hardenability control is today practiced in many types of parts. But it should not by any means be concluded that the hardenability should always be high; it must often be definitely low. The general rule is: Low hardenability for toughness, high hardenability for strength and for ease of hardening. These three categories, namely toughness, strength and hardening, may for clarity be illustrated briefly.

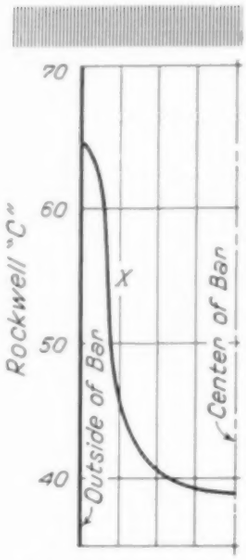
As an example of toughness, one may consider parts which should have an unhardened core so that the piece as a whole shall be tough. Examples are found in vibrating parts, such as air-hammers, where the surface must resist wear but the piece as a whole must not be brittle. By using a plain carbon steel of definitely low hardenability and hardening it in a water quench, the surface of the piece will be hard

By M. A. Grossmann
Director of Research
Carnegie-Illinois Steel Corp.

A paper, slightly condensed, read before the Western Metal Congress, 1938

and so will resist wear, but the core of the piece will fail to harden and will therefore be tough, thus imparting toughness to the piece as a whole.

By contrast, when the important consideration is strength, the hardenability should be high. Consider the case of an axle shaft. It is true that adequate strength of the shaft as a whole might be obtained even without hardening, by increasing the size of the piece. But the strength of the shaft could also be improved by heat treatment. And this is where hardenability is involved. Suppose the shaft is $1\frac{1}{4}$ in. in diameter, a common size. A plain carbon steel, even when quenched drastically, would harden to only a shallow depth near the surface, possibly $\frac{1}{8}$ in., so that the interior would be unhardened and would therefore be relatively less strong. In order that the whole piece shall harden, it is necessary to use steel of higher hardenability, which in quenching will harden not only at the surface but also in the interior.



Average Hardness Readings, Plotted Against Location Along Radius of Round Bar, Give a Hardness Distribution Curve, Edge to Center

Measuring Hardenability

Finally, hardenability was mentioned in relation to quenching. Most steels, even when they have low hardenability, can be hardened by quenching in water. But this is sometimes dangerous, since the parts may be of complicated shape, including more or less sharp angles, and the water quench may cause the piece to crack or suffer undue distortion. For such pieces of complicated shape it would then be desirable to quench the piece into a milder quenching medium, such as oil, thus reducing the quenching stresses. Clearly, in such cases, it is necessary to use steel of a higher hardenability, which hardens in the milder quench.

Hardened Bar, Cut and Tested for Hardness Edge to Center on Two Diameters

It is clear then that hardenability has to do with the **speed** at which steel must be cooled in order to harden it, or rather, the time occupied in cooling during the quench. Hardening is associated with the arrested transformation of a solid solution (austenite) stable at high temperature to a mixture of ferrite and cementite. Now the reaction rates in this behavior have been made clear by the work of Bain and Davenport. They showed that steel which has been heated for quenching, and is therefore austenitic, will, upon cooling, transform (to pearlite) most rapidly not at the critical temperature, 1333° F., but at a sub-critical temperature in the neighborhood of 1000° F., and that steel, in order to harden completely, must be cooled rapidly so that there is not enough time for this transformation to pearlite to begin. If it is cooled thus sufficiently rapidly, then as the quench proceeds to considerably lower temperatures, the supercooled austenite transforms to martensite and is hard.

This work by Bain and Davenport has thus shown that hardenability of steel is measured by the length of time required for the pearlite transformation in the 1000° zone. Another related estimate is made by French who determined the rate of quenching to prevent any formation of fine pearlite.

The test which has been employed most widely to measure hardenability is the Shepherd P-F test (**Metal Progress**, Feb. 1931, p. 51) which, in one of its forms, measures the thickness of a flat plate which just fails to have an "unhardened core" (determined by fracture or etching) when quenched in a definite manner.

Two additional proposals have been made at the last annual convention: The paper by Burns, Moore and Archer suggests using as an index of hardenability the ratio of two areas, namely the area under a hardness distribution curve as related to the area representing full hardening. Jominy and Boegehold suggest quenching a bar at one end under controlled conditions, and using as a measure of hardenability the distance along the bar which is found to be hardened.

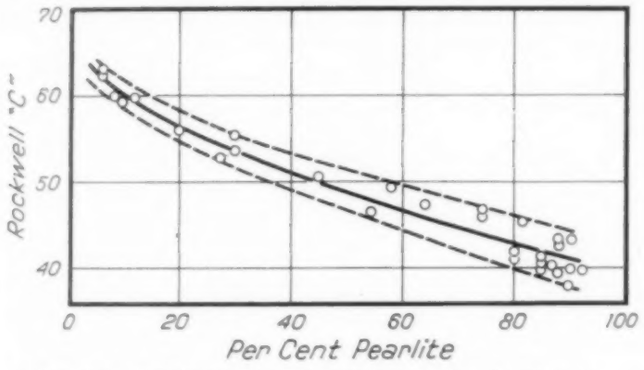
In these or any other methods of measuring hardenability by quenching, it is useful, and indeed important, to realize that there are certain characteristic behaviors during the hardening of a piece of steel and these will now be described.

Hardness Distribution Curves

One of the most common and most accurate methods for describing the hardness attained upon quenching is as follows: A cylindrical bar is quenched under selected conditions (dictated by the investigation or by the commercial

practice to be employed); after quenching, it is cut or broken in half, and ground to a smooth surface. Hardness readings are then taken across one or more diameters, commonly with the Rockwell machine because its range of hardness is suitable for quenched steels. An example is shown on the opposite page, below, and the hardness readings are averaged and a symmetrical curve plotted, such as the one shown at the top of page 374.

It becomes of interest to consider the significance of this curve. It is apparent at once that the outside of the bar is harder than the center. If we examine the outside portion of the bar with a microscope, we find that it consists entirely of martensite, without any fine pearlite. As we look toward the center of the bar, we soon encounter a small proportion of pearlite associated with the martensite, and as we progress further into the bar the proportion of this pearlite increases. The reason for this is clear from the conditions which obtain in a bar during quenching, since the outside



Rockwell Hardness Vs. Proportion of Fine Pearlite in a Microstructure of Mixed Pearlite and Martensite

of the bar in immediate contact with the quenching medium cooled most rapidly, and the inner portions of the bar, as they were further and further removed from the surface, cooled more and more slowly.

A feature of particular interest is the rather sudden drop in hardness at the region marked X. Now it has already been stated, and it is clear without further argument, that the presence of soft pearlite with the hard martensite results in a lesser hardness than when the structure consists of martensite alone. It is, however, not clear without further demonstration that the decrease in hardness would be **proportional** to the amount of pearlite, or whether some other factor enters.

The desired information may be derived by testing a number of sections of the steel and estimating the proportions of pearlite and martensite in the immediate neighborhood of each impression of the hardness machine. Rockwell hardness at each point was then plotted against the per cent of pearlite at that point and this chart indicates that as the percentage of pearlite increased, the decrease in hardness was regular — that is, there was no point at which a slight increase in pearlite caused a sudden drop in the hardness.

The Rate of Formation of Pearlite

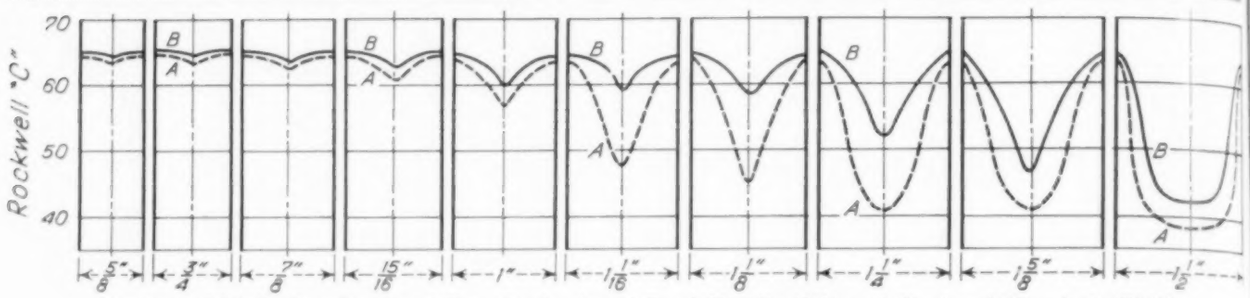
Reverting now to the first figure, it seems clear that if there is a sudden drop in hardness at region X, then this indicates a sudden increase in the per cent of pearlite at the region X, as is indeed found upon careful microscopic examination. In other words, if instead of plotting the hardness (from surface to center), we plot the per cent pearlite, we will obtain a diagram which is much the same as though the first one were turned upside down; near the surface the proportion of pearlite increases at first slowly, then increases rapidly and finally increases slowly toward the center.

Now it must be remembered that as one proceeds from the surface to the center of the bar, the successive regions encountered will have occupied more and more time in cooling in the quench; that is, the cooling time increases from the surface to the center. We thus come to a behavior which is of great practical importance in steel hardening and which may be stated as follows: A steel will harden completely (to martensite), if it is cooled at any quenching rate which is faster than the limiting rate characteristic for that steel. If the cooling is slightly slower than this limiting rate, a certain small proportion of pearlite forms during the quench, and as the cooling is slower, the proportion of pearlite increases. With increase in cooling time, the proportion of pearlite increases at first slowly, then more rapidly and again more slowly.

Up to now we have examined the rates of pearlite formation and their effects on hardness distribution within a single bar. But simple consideration will show that we may expect similar effects in a series of bars of different sizes. Let us consider the conditions obtaining at the center of a quenched steel bar.

The Pearlite Effect Vs. Bar Size

Assume a steel of any particular hardenability hardened under specific quenching conditions. If we consider the center of a quenched bar, there will be some (small) size which will harden fully at the center, without any pearlite. If we now consider a series of sizes, and consider the center of



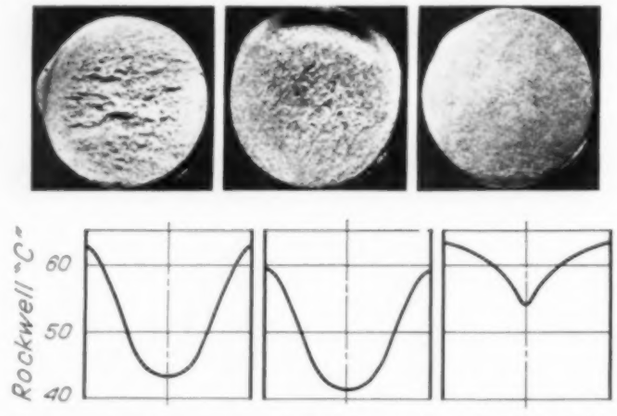
Hardness Distribution Curves of Two Steels, A and B, of Slightly Different Hardenability, Yet Which Show Great Differences in Condition After Standard Quench in Intermediate or "Critical" Sizes of Bar

each successively larger bar, we realize that with each increase in size the quenching rate at the center becomes somewhat slower. As the size of the bar is gradually increased, there will at first be a slow increase in proportion of pearlite (at the center), then a more rapid increase in proportion of pearlite, and finally again a somewhat slower increase in pearlite. Stating this in terms of center hardness of the quenched bar, we may expect to find, as we increase the size of the quenched bar, at first a slow drop in the center hardness as the bar size increases, then a rapid drop with further increase, and with still larger bar sizes a slower drop.

This behavior is indeed encountered in quenched steels, and is illustrated in a series of sizes from ⅝ to 1½ in. The hardness distribution that was obtained in the quenched pieces is shown in a series of hardness diagrams (bottom lines marked A). As the size of the piece increased from ⅝ in. to ⅞ in., the drop in center hardness was slight—C-63 to C-61. In the next three steps, however, with a total increase of only ⅛ in. diameter for the three, the drop was considerable, namely from C-61 to about C-45. Thereafter, with further increase in size, the drop in center hardness was again more gradual. The most marked change in center hardness took place in the neighborhood of 1⅛ in. diameter. It may thus be said that for steel of this hardenability, quenched under these quenching conditions, the most rapid change in center hardness is at 1⅛ in. diameter, and 1⅛ may thus be considered a "critical" size for this steel.

When we consider these matters in relation to practical hardening problems, we find that changes in center hardness must be reviewed carefully before making judgments as to hardenability, but when they are so reviewed they become a valuable index. Possibly this will become clear if we take another steel of slightly greater hardenability. As shown by curves marked **B** it will be found that they may nevertheless show great apparent differences in the neighborhood of the critical size as above defined. Suppose that in practice we are using a ¾-in. bar of steel **A**. Steel **B**, with its slightly different hardenability, will still give a hardness distribution that is approximately the same at this size, and indeed this is true for the whole range of sizes from ⅝ in. up to 1 in. diameter. In this range of sizes the difference in center hardness between the two steels is only 1 to 3 points in the Rockwell C scale. Contrasting with this similarity, we have the behavior shown in the small range of sizes 1⅛ in. to 1¼ in. diameter. Here the difference in center hardness may amount to as much as 12 points. This is in the neighborhood of the critical sizes for the two steels, and the rea-

(Continued on page 432)



Unsmoothed Fracture and Corresponding Hardness Distribution Curves Showing That "Hardened Rim" Is Not Completely Hardened, and That Steel With Complete Porcelanic Fracture May Be Somewhat Soft at the Center

Study of Grain Size in hardened high speed

Determination of grain size of prior austenite in quenched and tempered high speed steel requires the use of a new etching reagent and sometimes a light repolishing. Once the technique is known, it has proven exceedingly valuable in diagnosing tool troubles and in establishing conditions necessary for best service of tools in shop operation

IT HAS FREQUENTLY BEEN SAID THAT MUCH INDUSTRIAL research merely discovers the reason for doing things the artisan has done since time immemorial. A case in point is the recent interest about grain size in steel. Before the advent of chemistry and metallography, a bar of tool-steel would be broken at the end to determine its carbon content and to judge its "body." Only recently has that indefinite term "body" been given some precise significance. Among other things, it involves hardenability and toughness, and these in turn are closely related to the grain size existing in the austenite at the moment of quenching for hardening. The steel worker, without the aid of a microscope, judged grain size in a fractured bar by eye, and two years ago Vilella and Bain showed that a series of fractured bars carefully graded by an experienced eye possessed an increasing and definitely proportional size of primary austenitic grain, as determined by most modern laboratory equipment (see METAL PROGRESS, September 1936).

We in the research laboratory of Universal-Cyclops Steel Corp. have long been attempting to determine those factors which make for excellent performance in hardened high speed tools, and have never doubted but that fine grain and fine fracture are a prime requisite for quality. These are, however, qualitative terms, so we have gradually evolved a method of measuring the grain size of quenched and tempered high speed. Use of this method for plant control and for studying unusually good or unusually poor tools has convinced us that grain size *in the tool ready for work* must be controlled if uniform performance is to be expected. Likewise we are led to believe that the optimum grain size is not the same for all classes of tools. Data in this respect are far from complete, but it would appear that lathe tools made of high speed steels will generally show best results at grain size about 10 (measured as shown below), whereas optimum grain in threading taps is considerably finer — about 18.

Thus it may eventually be possible to establish definite austenitic grain size for each type of tool if the best service is to be obtained under definite operating conditions. Undoubtedly tools requiring considerable toughness must have finer austenitic grains than tools where toughness is not a factor and maximum cutting results are desirable. It is a fact that the best *cutting* results are obtained from steels that are coarse grained, but because of the toughness requirements high speed steels cannot always be hardened for maximum cutting results. In such cases a compromise between tough-

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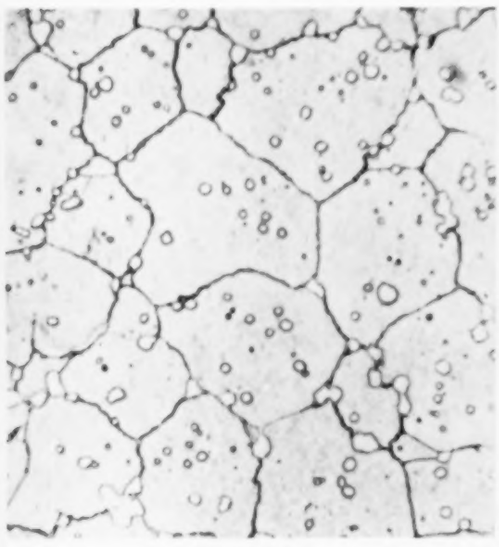
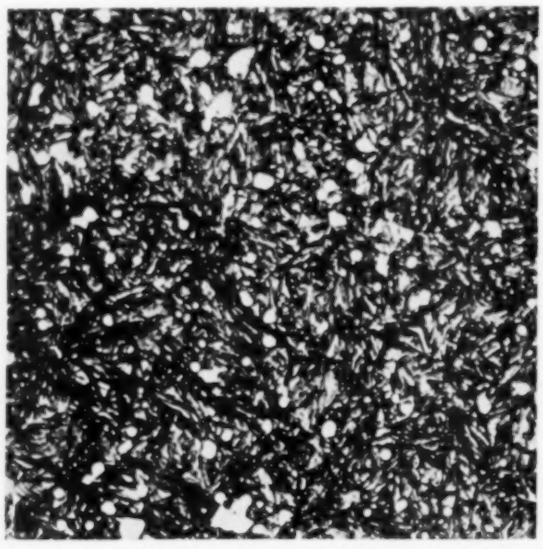
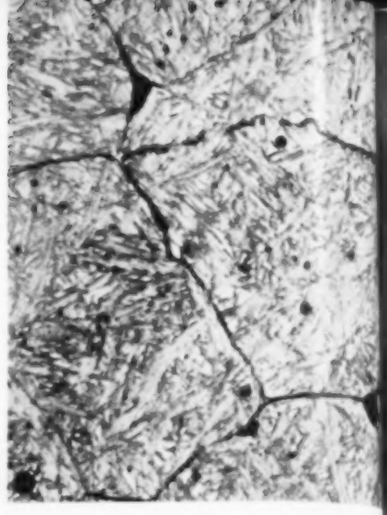
Micros in Column at Right Are Etched After Tempering and Have Average Grain Size (Intercept Method) as Noted

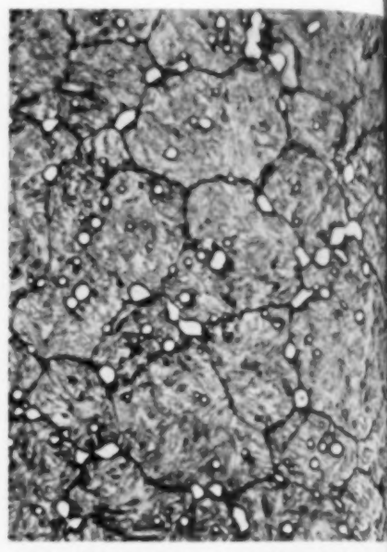
Micros in Row Below Are of Same Piece of Molybdenum-Tungsten High Speed Steel. Grain Size 10 (Intercept Method). Left is as hardened, etched with nital. Center after tempering, etched with nital. Right is same, but etched with modified reagent and lightly repolished to show grain boundaries

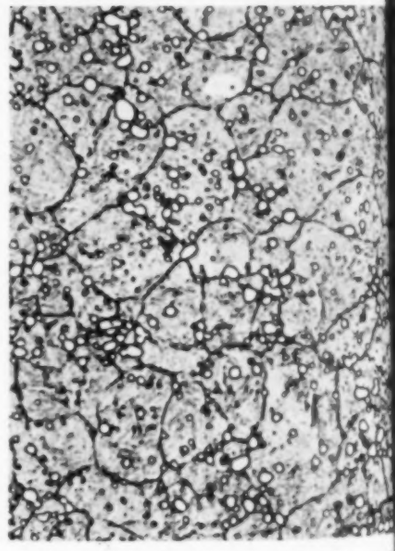




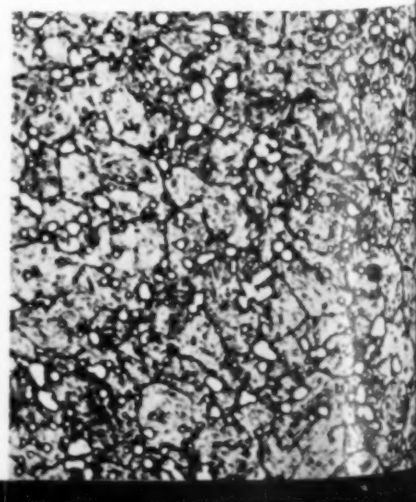


Grain Size 5 Above; Grain Size 1





Grain Size 15 Above; Grain Size 2



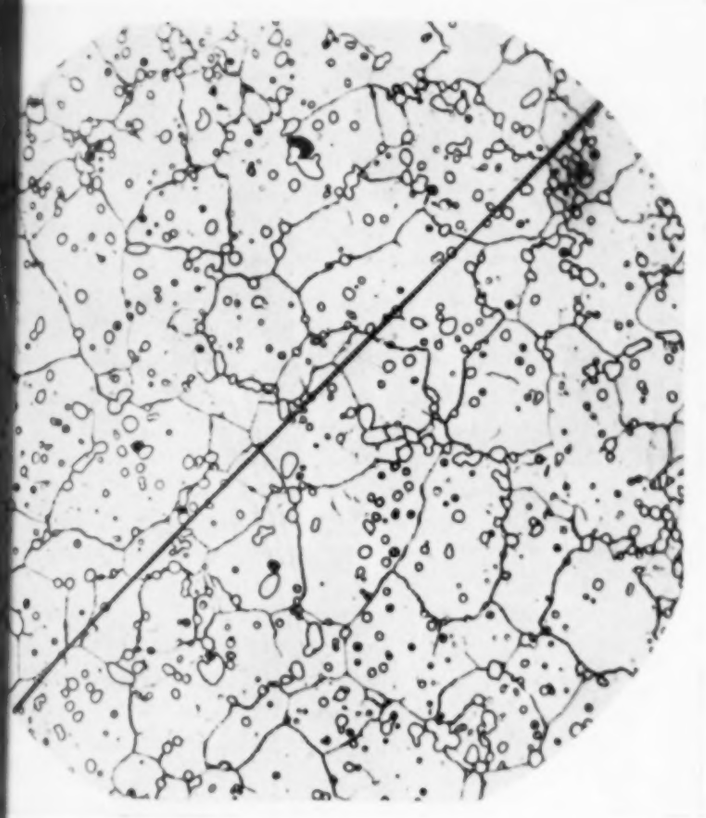
ness and cutting ability must be adopted for optimum results.

Since our preliminary results have proven of so much advantage to us and to some of our customers in correcting occasional machining troubles by correcting the heat treatment to give the proper grain size in the tools, it is believed that publication of our laboratory methods will be interesting to many other metallurgists.

The austenitic grain size of any high speed steel, immediately after quenching, can readily be determined by microscopic examination after the usual etch of a polished spot in nital solution (4% to 10% nitric acid in alcohol). However, there are numerous occasions where the metallographer examines the specimens in the "hardened and tempered" condition — for example, a tool that has failed in service — and, unless the specimen is "under tempered," it is difficult to determine accurately the austenitic grain size with the above technique.

The method of etching martensite (quenched carbon steels) to show the original austenite grain has been described in the technical literature by J. R. Vilella. He recommends a tepid solution of 1 g. picric acid and 5 cc. concentrated hydrochloric acid in 95 cc. ethyl alcohol. High alloy compositions, like high speed steels whether straight tungsten or tungsten-molybdenum types,

do not lend themselves to etching with solutions of picric acid; they are more generally etched with nital solutions, ranging from 2% nitric acid to as much as 10% nitric acid in alcohol. From Vilella's reagent we adopted the use of hydrochloric acid in our regular "nital" etch, and finally selected as most suitable a reagent containing up to 10% hydrochloric acid and 3% nitric acid in methyl alcohol. This etching solution appears to be quite capable of developing the original austenite grain. There may be other etching solutions even more satisfactory, and it is the writers' hope that such perfected etching solutions may eventually be developed.



ened High Speed Steel With Thread Line Showing Method of Count-cepting Grains. In this sample, 13 grains intercept the 5-in. diameter

The etching of "as hardened" high speed steel by nital for austenitic grain size usually requires from 3 to 6 min., a factor depending upon the composition of the steel and the effectiveness of the hardening. Etching the same section after tempering reveals the character of the martensite but usually no trace of the original austenite grain can be seen. (Typical micros are shown on page 378.) The addition of the hydrochloric acid to the etching solution appears to accentuate the attack along the grain boundaries and at the same time suppresses the attack on the martensite, and the microstructure shown in the series of views ranged in a column gives the result. They may be compared with that one where the conventional nital etch has been used.

The use of the suggested etch requires a slightly different technique. The specimens are polished in the usual manner and etched by being inverted in a watch glass containing enough of the solution to cover the surface. Action may take from 2 to 10 min., depending on the analysis and its heat treatment. Specimens that darken may have to be repolished lightly, just enough to remove the general tone and leave the austenitic grain boundaries clearly revealed. This repolishing procedure is more necessary as the grain becomes finer, because the fine grains are not as distinct as the coarse grain boundaries.

Grain Size Estimation

Having revealed the grain size of the prior austenitic structure, the next problem was to characterize it quantitatively. Various methods have been suggested and used by microscopists interested in metals, rocks and organic substances. The one principally used by metallographists is to compare the sample under observation with a series of standard micros, whose grain size area decreases in geometrical proportion.

This method did not seem to be sufficiently discriminating at the smaller grain sizes, so a modified "intercept" method was adopted by us. It is obtained by counting the number of grains that intersect a line 0.005 in. in length at ten random points on the specimen. The average of these ten counts is taken as the grain size of the specimen. A small integer denotes a large grain size while larger numbers denote smaller grain sizes.

Grain count over the 0.005-in. line is made

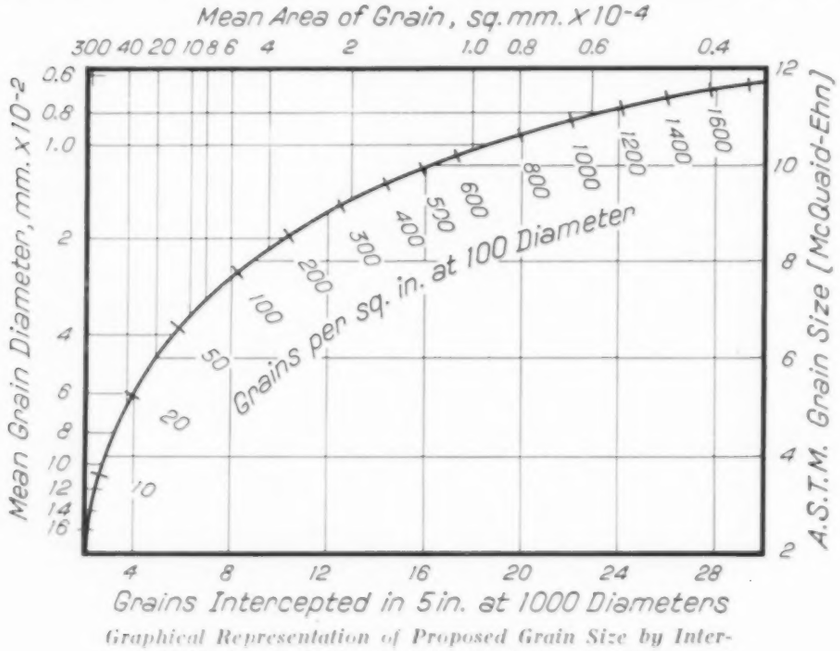
by counting the grains intersecting a 5-in. line on the ground glass of a microscope where the image of the specimen is projected to a magnification of 1000 diameters. An ordinary black thread stretched across the middle of the field, and on the bellows side of the ground glass, establishes a straight line across the field screened off to exactly 5 in. in diameter. Actual counting of the ten locations requires approximately 1 to 3 min., depending on the type of specimen. It may be convenient to use a graduated eyepiece to make the counts. In this case, the central division marker is extended to the edges of the field, and the field adjusted to include 0.005 in. of the specimen. The average of ten counts is then determined as previously indicated.

It is realized that this method of characterizing grain size is not the same as the method almost universally used for measuring grain size in carbon and low alloy steel. (Actual relationships are given in the accompanying curve.) However, the McQuaid-Ehn standard in turn is different from the method used by metallurgists in the copper and brass industry. The method now suggested by us is thought to be somewhat better adapted to the structures peculiar to high speed steels. It will also be evident from the chart below that it gives a very open scale at the grain sizes suitable for good cutting tools, whereas the same by McQuaid-Ehn or Shepherd test would be ranked as "10 or finer."

Use for Control and for Research

As remarked at the outset, grain size in the tool *as it is used* is an important criterion, and by our method is readily determined. It can immediately be utilized by any metallurgist if he will determine the grain sizes of some exceptionally good tools, establish the average result as standard, and then check the grain size of tools as made for equivalent duty. In our opinion the prime factors causing grain growth prior to quenching — given a standardized atmosphere — are time and temperature (or, rather, time at *actual* temperature), and these two may readily be adjusted for best results.

Obviously, once grain size can be accurately measured, the influence, real or reputed, of many other factors on grain growth can be investigated, as well as the influence of grain size on other physical properties of high speed toolsteel. A few of these interesting questions are now being investigated, as opportunity permits, in our laboratory.


Mean Area of Grain, sq. mm. X 10-4
300 40 20 10 8 6 4 2 1.0 0.8 0.6 0.4
Mean Grain Diameter, mm. X 10-2
0.6 0.8 1.0 2 4 6 8 10 12 14 16
Grains per sq. in. at 100 Diameter
10 20 50 100 200 300 400 500 600 800 1000 1200 1400 1600
A.S.T.M. Grain Size (McQuaid-Ehn)
12 10 8 6 4 2
4 8 12 16 20 24 28
Grains Intercepted in 5 in. at 1000 Diameters

Graphical Representation of Proposed Grain Size by Intercept Method in Relation to Other Methods of Measurement

Zinc Alloy Die Casting

an industrial achievement

Simultaneous developments of improved casting machines and perfected zinc-base alloys are responsible for a great increase in the size, quality, strength and permanence of modern die castings. These new materials have been accepted by many engineers, designers and canny purchasers for an increasing number of applications in the mass production industries

DIE CASTING OF ZINC ALLOYS IS A PRODUCT OF the present century. While commercial castings were produced as early as 1900 the consumption had not become sufficiently important to warrant separate listing in Metal Statistics until 1926, at which time the total was 13,500 tons. Last year's official figure is not yet available but will approach 90,000 tons. Such a rapid rise in popularity in this brief period was due to tremendous improvements in quality made possible by unceasing efforts on the part of both alloy manufacturer and casting producer, working in close coordination.

Much has been written about specific applications of die castings and the design of dies for the production of the parts. Little appears in the literature concerning the reasons for the abrupt change in attitude of industry in general toward these alloys and this method of fabrication. It is hoped that this paper will help to round out and clarify what has been published already concerning this aspect of the matter.

For the benefit of any to whom the process is new, die casting may be defined as the art of producing metal objects by forcing a molten alloy into a closed steel die by means of pressures exceeding that of gravity. Machines are used for the purpose, which consist essentially of a frame to hold the die, a mechanism to open and close it, a furnace and melting pot to hold a supply of molten metal and a device for forcing a portion of this molten metal into the die. In the commonly used method a piston, actuated by air, hydraulic or mechanical force, acts on the metal to force it into the die. In another type of machine air pressure is applied directly to the molten metal. The sketch on the next page shows the essentials of operation of a so-called plunger type machine.

This process lends itself to the production of castings in alloys based on lead, tin, aluminum, copper, magnesium, and zinc. By virtue of a fortuitous combination of melting point, strength and cost, zinc alloys are by far the most widely used, representing about three quarters of all the die castings made today. While commonly referred to as zinc die castings, they are, in truth, zinc *alloy* die castings, since unalloyed zinc does not have sufficiently good physical properties to be of engineering interest.

Sixteen years ago when zinc die castings were being produced in relatively small

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A paper presented at the Western Metal Congress, 1938

quantities and almost entirely for ornamental purposes, the alloys in common use were as follows (zinc representing the balance):

Designation	Composition—Per Cent Aluminum	Copper	Tin
5-3	5.0	3.0	...
12-3	12.0	3.0	...
6% tin	0.5	2.8	6.0

Some impression of the properties and aging qualities of these older alloys can be obtained from the data in the large table. Data on alloy 4-3, which is quite comparable though slightly superior to 5-3, are given because incomplete information is available for the latter alloy.

The steam test referred to in the table is the accepted method of detecting susceptibility to intergranular corrosion which may occur in service in improperly formulated alloys. In it the castings are exposed to an atmosphere saturated with moisture just below the boiling point of water. It is used as an acceptance test to reveal improper composition, particularly contamination by lead and tin. Correlations with ordinary exposure tests over a period of many years have shown that no zinc alloy which resists grain boundary corrosion in ten days of exposure to this atmosphere will give trouble in service under the actual conditions to be met in use.

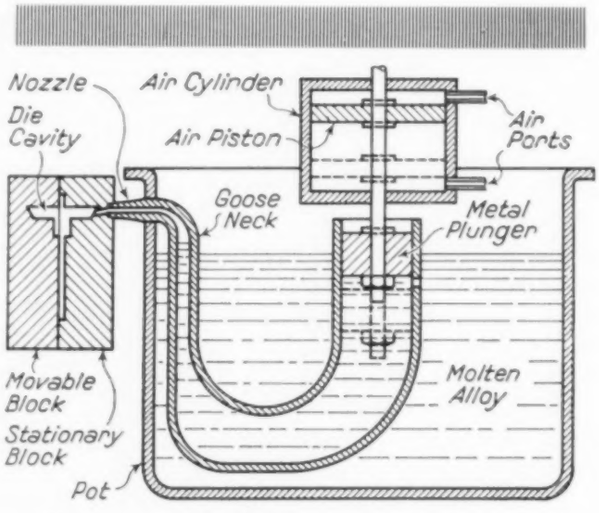
These data show clearly one reason why zinc alloy die castings were not used in large tonnage in 1922. The properties of the alloys as cast were suitable for many applications, but retention of both strength and size was not to be relied upon. It was obvious that if this use of zinc was to expand beyond a very narrow field of applications drastic improvements were imperative.

The limited scope of this article does not allow for a *résumé* of the interesting, almost romantic, series of events which culminated in the present strong, stable, dependable group of alloys known quite widely by our own registered trade name "Zamak," but also marketed under various identifications by licensees under the New Jersey Zinc Co.'s patents. The details of this evolution may be found in papers by Messrs. Peirce and Anderson, Brauer and Werley in bulletins of the Research Laboratory, New Jersey Zinc Co., and in *Metals and Alloys*, June 1930 and May 1934, and by H. L. Evans in *The Metal Industry* (London) July 30, 1937.

Various engineering societies have established standards or tentative standards covering these new alloys in the form of castings, and these will be found in the publications of American Society for Testing Materials and Society of Automotive Engineers.

The success which attended the efforts toward improvement can be described no more forcefully than by the reading of the large table, in which are given comparable figures for properties and aging treatments for the old alloys and for those in use today.

It will be noted that the data for the new alloys include figures illustrating the effect of *dry heat* at 95° C. These were included to show that practically all changes that occur in these modern alloys during the steam test are caused by the temperature of the test, and not by corrosion. It must be strongly emphasized that this is true *only* when the chemical composition of the castings lies within the close limits set in the specifications for these alloys.



Diagrammatic Sketch Showing Principle of Operation of Plunger Type Die-Casting Machine

While absolute permanence on aging cannot be claimed for the new alloys, their practical permanence, particularly in the cases of alloy No. 3 and alloy No. 5, is excellent. The small changes in properties which do occur are the result of simple aging phenomena, the nature of which is now well understood. (A scientific exposition of the facts has been given by M. L. Fuller and R. L. Wilcox in two papers in *Transactions*, A.I.M.E., 1935

and 1936.) One can therefore use these alloys with the certainty that their properties will not alter in an unpredictable manner under various service conditions. This makes it possible to consider the use of zinc alloy die castings in engineering applications for which the alloys of 15 years ago were definitely unsuited.

regard to strength, soundness and dimensional uniformity.

Die design has kept pace with these other advances by directing the flow of metal in such a way as to produce smoother surface, greater soundness and higher strength. Die casters have also become more and more conscious of the

Relative Properties of Zinc Die Castings, 1922 Vs. 1938

Property and Aging Period	Old Alloys (1922)			New Alloys (1938)		
	4-3	12-3	6% Tin	No. 2	No. 3	No. 5
Impact strength, ft-lb. *(b)*						
As cast	5.5	1.2	1.0	19	20	18
10-day steam, 95° C.	0.25	*(a)*	0.25	1	22	11
10-day dry heat, 95° C.				2	23	16
4-year indoor aging	0.25	0.25	0.25	5	22	20
7-year indoor aging *(c)*				2	17	18
Dimension change, in. in 6 in.						
10-day steam, 95° C.	0.268	*(a)*	0.065	0.0128	0.0038	0.0033
10-day dry heat, 95° C.				0.0144	0.0015	0.0023
4-year indoor aging	0.031	no data	0.004	0.0044	0.0005	0.0009
7-year indoor aging *(c)*				0.0091	0.0011	0.0007
Tensile strength, psi.						
As cast	41,700	38,500	24,900	47,900	40,300	45,400
10-day steam, 95° C.	9,300 *(a)*	*(a)*	9,700	45,100	33,200	35,700
10-day dry heat, 95° C.				45,500	34,400	37,400
4-year indoor aging	24,800	17,700	20,000	49,200	34,600	38,200
7-year indoor aging *(c)*				48,700	32,900	37,400
Elongation, % in 2 in.						
As cast	2.5	no data	no data	5.1	4.7	4.9
10-day steam, 95° C.	0	*(a)*	no data	1.0	5.5	1.8
10-day dry heat, 95° C.				1.4	9.0	6.6
4-year indoor aging	0	no data	no data	4.1	7.5	6.9
7-year indoor aging *(c)*				3.1	8.1	5.6

Notes: *(a)* Specimens disintegrated. *(b)* Unnotched bar, ¼ x ¼ in. *(c)* Data for newer alloys are indicative of their stability; no corresponding figures available for the older alloys

Progress in the Die-Casting Art

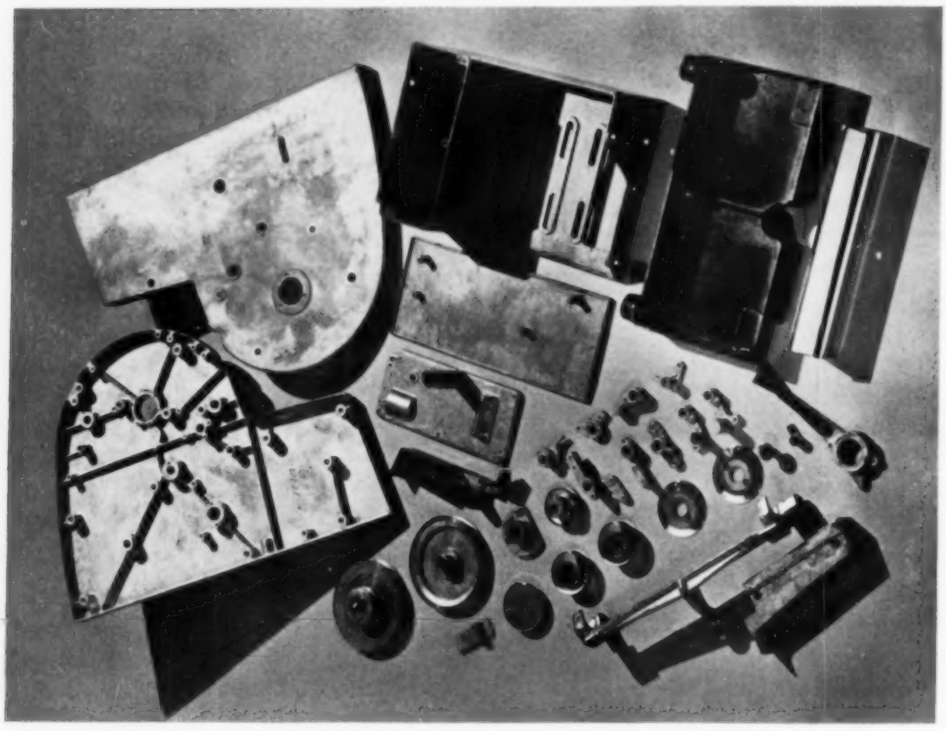
All this work of improvement in metals would have had little significance had it not been for the coincidental efforts of those engaged in the production of castings. No matter how excellent were the characteristics of the alloys when cast in simple test bars, they would have failed to interest the designer unless intricate shapes, light sections, fine surface and close dimensions could be obtained, not only on a few hand-picked samples, but with no variation of commercial significance between any two castings out of a run of thousands.

The improvement in foundry equipment has been rapid and continuous. From low, variable pressures and inadequate devices for closing the dies, the industry has gradually evolved machines sufficiently powerful to hold the die closed against metal pressures as high as 2000 psi., thus resulting in major improvements in importance of the control of metal and die temperatures as well as pressure.

These factors have all had a bearing on the finished product, and it is a source of gratification to all who have contributed to the evolution to compare the light, thin-sectioned, smooth castings of today with the rough, bulky ones of 15 years ago.

The engineer is not interested in obtaining one die casting of satisfactory properties but requires that he be supplied with thousands of castings of closely reproduced characteristics. The die caster has accomplished this by rigid control of his various casting conditions, including the rate of production.

As pointed out earlier in this paper, the desirable qualities of the present-day castings can be obtained only when the alloys are held within the specification limits set for them. This requires extreme care on the part of the die caster, not only in respect to the purity of his



Thirty-Nine Parts— 58% of the Total Weight — of the New Rotary Duplicating Machine Shown on the Opposite Page Are Zinc Alloy Die Castings

alloys, but also in the exclusion of all harmful metallic elements from his casting department. It also requires accurate analytical inspection of his product both for impurities and alloying ingredients. Since most of these elements are present in extremely minute quantities, the most satisfactory tool for such inspection is the spectroscope, and many die casters are now using this means of checking the chemical composition of their product.

Engineering Acceptance

It would be unfair in pointing out the factors back of the evolution of the die-casting industry to neglect the consumer. The imagination and ingenuity shown by designers in utilizing the economic advantages of the process have been a constant source of stimulation to the metallurgical industry. For example, it took a great deal of faith and imagination on the part of the engineers responsible for the design of air brakes for railroad freight cars to depart from established methods and materials for the vital air valves and other important parts of the newest brake. That they were justified in this faith is amply demonstrated by the absence of any failure attributable to the zinc castings in more than five years of hard service on thousands of freight cars.

In his constant search for economical methods of fabrication, the engineer has kept before him the ideal of converting molten metal into a final product in one operation. It is not immediately clear to those unfamiliar with the process how closely the die-casting method approximates this ideal. The molten alloy in the pot is converted by a single stroke of the plunger into a strong, accurately dimensioned casting requiring only a minimum of trimming and machining to be ready for use — sometimes no machining at all!

The possible savings have been of interest to many consuming industries. Low cost alone, however, does not account for the wide acceptance of die castings by engineers. The castings must have certain essential properties, together with a high order of reliability. It is the combination of low production cost with good physical properties and reliability which accounts for their wide and ever-widening adoption.

The engineer designing parts to be produced as zinc alloy die castings will find experi-

ence his best guide. Over a period of many years die casters and designers have been building up a wealth of experience which can be drawn upon in the design of new parts. The ordinary mechanical properties, such as those listed in the table, can be used to a limited extent in design but are, perhaps, of greater value as a means of comparing the alloys with each other.

Fatigue, which is a limiting factor in many designs based on common engineering materials, does not appear to be a vital factor in the case of zinc alloy die castings. In many years we have seen only one or two cases where failure might have been caused by fatigue.

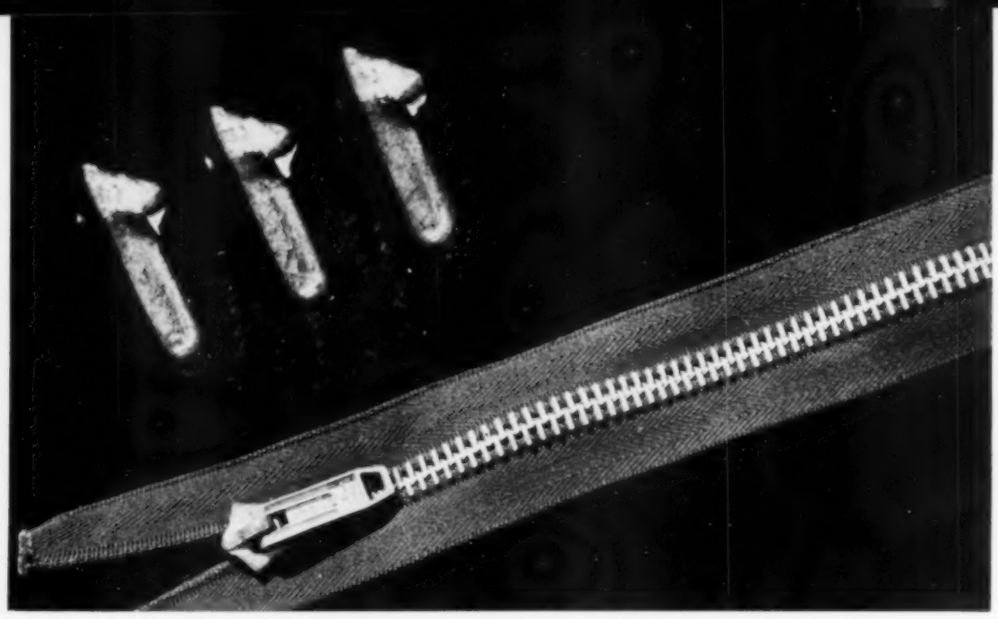
In recent years the creep of materials under continuous stress has become important in many branches of engineering. While this type of deformation does not constitute a design problem in the case of many zinc alloy die castings, it must nevertheless be kept in mind and precautions taken when relatively heavy loads are to be carried continuously. Experiences in the field have provided the die caster with valuable knowledge of safe limits, and years of testing under constant stress conditions in the laboratory have made it possible for us to assist in the design in specific instances.

The Modern Alloys

It perhaps would be well to review at this point the differences in properties and behavior of the new alloys, since these differences are frequently the basis for choice in specific applications.

The alloy listed as No. 2 in the table (Zamak-2) has the following nominal composition: 4.1% aluminum, 2.7% copper, 0.03% magnesium and balance zinc of highest purity. It corresponds to Alloy XXI of the A.S.T.M., Alloy 921 of the S.A.E., and Alloy F-11 of the A.F.A. It has the highest tensile strength and Brinell hardness. It age hardens, slowly at room temperature and more rapidly at elevated temperatures, with definite losses in ductility and with an increase in dimensions. Where dimensional stability and high ductility are not required, the alloy enjoys use because of its strength and hardness. The figures given in the table for dimension change are all gradual *expansions* in the finished casting taking place under various aging conditions after the initial shrinkage of 0.0063 in. in 6 in. is completed.

Alloy No. 3 in the table (Zamak-3) has the following nominal composition: 4.1% aluminum, 0.04% magnesium, and balance zinc of



Slide Fastener — Each Element Is Die Cast Separately and Directly on the Tape. The three elements shown are magnified 10×

highest purity. It is therefore substantially Zamak-2 without the copper. It corresponds to Alloy XXIII of the A.S.T.M., Alloy 903 of the S.A.E., and Alloy F-12 of the A.F.A. Its initial shrinkage is 0.0040 in. in 6 in.; this means that a bar 8 ft. long would shrink only $\frac{1}{16}$ in. after removal from the mold. The change in dimensions of a die casting of this alloy *after* machining can be reduced to less than 0.0003 in. per in. by allowing the casting to age five weeks at room temperature or by heat treating for 6 hr. at 100° C. before machining. The maximum expansion noted in this alloy after seven years of indoor aging was 0.0002 in. per in.

This alloy retains its ductility unimpaired over long periods of exposure at room temperature or at temperatures up to 100° C. Its tensile strength and hardness are slightly lower than the other two modern alloys.

Alloy No. 5 (Zamak-5) contains 4.1% aluminum, 1.0% copper, 0.03% magnesium and the balance zinc. It corresponds to Alloy 925 of the S.A.E., and is now under consideration by the A.S.T.M. Its initial shrinkage is 0.0056 in. in 6 in. It is slightly lower in tensile strength and hardness than Alloy No. 2, but is considerably superior from the viewpoint of stability of strength and dimensions.

Under room temperature conditions, it maintains its ductility unimpaired over long periods of aging and undergoes only a very small expansion. Long periods of service at elevated temperatures cause this expansion to about equal and offset the initial shrinkage after casting; this causes some loss of ductility without, however, rendering the alloy seriously brittle.

It will be readily appreciated that it is impossible in the small space of this general paper to describe these alloys in sufficient detail to permit the engineer to select the alloy best suited to his purpose. It would be advisable to consult the die caster before designating the alloy in order to utilize his valuable experience.

In closing, it is hoped that this paper has visualized the long strides in practice and in alloys during the past decade. It is particularly hoped that the reliability of the modern zinc alloys is clear. In developing the discussion, we have tried hard to avoid creating the improper impression that zinc alloy die castings can be applied universally. This, of course, is untrue since zinc alloys, like all other materials, have definite limitations beyond which we cannot safely apply them. Fortunately for the designer who wishes to make use of the economies inherent in die casting, the limits of usefulness are very wide indeed. Despite the development of many new uses in recent years, there is ample reason to believe that the limits of application are still a long way in the future.

While the engineer already familiar with die casting can draw on his own experience to a certain extent, it is not amiss to reiterate the suggestion that new applications be discussed with an experienced die caster at a very early stage. This will insure that the ultimate design will take advantage of the accumulated knowledge available and will be such as to combine the greatest economy in casting with the most effective utilization of the properties.

METAL PROGRESS APRIL, 1939; PAGE 387

Properties of Heat Treated Nickel Steel Castings

By F. J. Walls and T. N. Armstrong

From a Paper "Nickel Cast Iron and Nickel Steel" for Western Metal Congress, 1938.

	Chemical Composition						Tensile Properties				Impact Test, ft-lb. I = Izod C = Charpy (Keyhole notch)
	C	Mn	Ni	Cr	Mo	V	Yield psi.	Ultimate psi.	Elongation %	Red. of Area %	
Medium Carbon Steel, Normalized and Drawn											
Basis	0.30	0.70	—	—	—	—	45,000	79,000	29.0	47.0	I-34
Low Carbon, 2% Nickel, Normalized and Drawn											
Expected range	0.20 max.	0.60 to 0.90	2.00 min.	—	—	—	45 to 55,000	75 to 85,000	32 to 25	65 to 45	—
Individuals	0.19	0.81	2.20	—	—	—	50,000	80,000	28.0	59.0	I-58
	0.18	0.93	2.20	—	—	—	53,300	84,000	30.0	61.0	I-59
	0.17	0.82	2.18	—	—	—	50,800	80,200	30.5	62.5	I-64
Medium Carbon, Nickel-Vanadium, Normalized and Drawn											
Expected range	0.28 to 0.35	0.80 to 1.10	1.40 to 1.75	—	—	0.08 to 0.15	60 to 70,000	90 to 100,000	29 to 25	60 to 45	—
Individuals	0.26	0.97	1.54	—	—	0.11	60,500	90,000	25.5	51.0	I-47
	0.28	0.91	1.62	—	—	0.12	64,000	94,000	27.0	55.0	I-57
	0.30	0.81	1.52	—	—	0.11	66,200	96,000	27.5	55.0	I-56
Nickel-Molybdenum, Normalized and Drawn											
Expected range	0.20 to 0.30	0.60 to 1.00	1.25 to 2.00	—	0.25 to 0.40	—	55 to 70,000	85 to 95,000	28 to 22	55 to 45	—
Individuals	0.24	0.65	1.62	—	0.40	—	67,200	95,000	26.5	53.5	I-52
	0.24	0.64	2.15	—	0.33	—	70,000	92,500	24.0	50.0	I-60
	0.31	0.95	1.29	—	0.27	—	60,000	90,200	29.0	46.5	—
Nickel-Manganese, Normalized and Drawn											
Expected range	0.26 to 0.33	1.35 to 1.65	1.25 to 1.50	—	—	—	60 to 70,000	90 to 105,000	28 to 22	60 to 45	—
Individuals	0.27	1.41	1.40	—	—	—	61,000	99,200	24.5	57.5	I-41
	0.28	1.62	1.43	—	—	—	69,800	96,500	27.0	57.0	I-63
	0.29	1.56	1.43	—	—	—	61,000	105,000	25.0	56.0	I-41
Nickel-Chromium-Molybdenum, Normalized and Drawn											
	0.33	0.79	1.44	0.76	0.26	—	87,000	112,000	19.0	44.0	I-45
3% Nickel Steel, Normalized and Drawn											
	0.35	0.80	3.05	—	—	—	67,700	98,000	27.0	49.0	I-49
Various Cast Nickel Steels, Quenched and Tempered											
Ni-V Oil quenched Drawn 1250°F.	0.33	1.05	1.58	—	—	0.10	101,700	115,000	19.5	48.0	—
Ni-Mo Brine quenched	0.32	0.68	2.75	—	0.33	—	189,000	223,750	12.0	52.0	—
Ni-Cr Water quenched Drawn 1050°F.	0.36	0.85	1.80	0.70	—	—	130,700	141,500	15.0	38.0	—
Ni-Cr-Mo Water quenched Drawn 1150°F.	0.34	0.71	1.63	0.56	0.24	—	150,000	166,500	13.5	35.0	—
3% Ni Water quenched Drawn 1050°F.	0.29	0.75	3.57	—	—	—	124,500	130,700	16.0	42.0	—
Impact Values (Average of 4 or more) at Low Temperatures											
Ni-V	0.24	0.79	1.52	—	—	0.09	67,000	88,500	29.5	55.0	C-35 at 70°F. C-24 at -50°F.
Ni-Mo	0.24	0.64	2.15	—	0.33	—	68,700	88,600	28.0	54.5	C-36 at 70°F. C-26 at -50°F.
Ni-Mn	0.30	1.50	1.50	—	—	—	64,500	96,200	27.0	52.0	C-28 at 70°F. C-20 at -50°F.
2¾% Ni	0.15	0.58	2.90	—	—	—	61,200	76,800	33.0	55.5	C-32 at 70°F. C-20 at -75°F.
	0.17	0.36	2.57	—	—	—	54,000	76,000	32.0	62.5	C-39 at 70°F. C-21 at -75°F.
	0.24	0.62	2.39	—	—	—	61,500	81,700	32.0	53.5	C-33 at 70°F. C-19.5 at -75°F.

Economical use of these alloys for hand tools emphasizes their advantages for power equipment parts

Stresses and shocks take their toll even of hand tools. Cutting edges are dulled. Wrenches, pliers, hammers and such tools are damaged. Handles and shanks are broken as a consequence, so industry today is turning more and more to the use of Nickel alloy steels.

Light in weight, hand tools of Nickel alloy steel possess toughness, rugged strength, and excellent heat-treating qualities. They outlast hand tools of other materials many times over. They are more economical to use and maintain, and lower in ultimate cost.

The forces that destroy hand tools also shorten the life of power-operated equipment. Multiplied a hundred-fold, wear, high stresses and heavy shocks are constantly imposed on moving parts. The need for metals that will withstand this punishment is therefore proportionately greater.

The Nickel alloy steels possess in high degree the qualities required. Economical to use for hand tools, they also assure for machinery parts durability and longer life. Consultation on problems involving their application is invited.

1. These wrench sockets, manufactured by Plomb Tool Company, Los Angeles, are made of Nickel-molybdenum steel.

2. Dinging hammers and small ball peen hammers of various types, manufactured by Plomb Tool Company, Los Angeles, are made from Nickel alloy steels.

3. Bridgeport Hardware Company wrenches of S.A.E. 4650 Nickel-molybdenum steel.

4. Nickel alloy steel heavy duty screw driver made by Stanley Tools, New Britain, Conn.

5. Various types of heavy-duty pliers and pincers manufactured by Wm. Schollhorn Company, New Haven, Conn., from Nickel-chromium steel.

THE INTERNATIONAL NICKEL COMPANY, INC., NEW YORK, N. Y.

New Copper-Silicon Alloys

rods, wire, sheet, plate

They have the strength of mild steel and the corrosion resistance of copper, and can be worked in the blooming mill, pipe mill, plate mill and sheet mill as readily as steel. Since weldability is also excellent, and price moderate, they form the copper industry's reply to the competition from stainless steel

IN AN ARTICLE PUBLISHED LAST MONTH CONCERNING the historical development of the copper-silicon alloys and their properties as castings, the constitutional diagram was reproduced on page 261. It was shown that copper and silicon form alpha solid solutions (face-centered cubic space lattice), the limit of solid solubility being about 4.1% silicon at room temperature. The copper-rich end of this diagram is analogous to that for many other common binary copper alloys; alpha solid solutions are found containing up to 9.8% aluminum, 22% manganese, 0.5% phosphorus, 16% tin (bronzes), or 39% zinc (brasses). Since the commercial silicon alloys contain 4.0% silicon max. with a modicum of a third element it would be anticipated that these ternary alloys would also be alpha solid solutions, and this is in fact true. Microstructure of the rolled and annealed metal shows well-developed, stable crystals with no second constituent (except the iron-containing "P.M.G. Alloys," which show particles probably consisting of iron silicide, iron having only about 0.15% solid solubility in copper).

The commercial copper-silicons, therefore, are not hardenable by heat treatment nor aging; however, they do work harden very rapidly so that softening anneals are necessary during any extensive processing.

In the cast, unworked form, the copper is hardened by the silicon in solid solution, the stranger atoms acting as effective "knots" to interfere with slip in the cubic lattice. In common with this type of hardening by solid solution effect, the ductility — as measured by contraction of area and elongation in a tension test — remains high. This specific effect on strength (and hardness) rather increases as the percentage of silicon increases, as shown by the following table for annealed rods:

Alloy	Tensile Strength	Elong. in 2 In.	Conductivity	
			Electrical	Heat
Copper	33,000	48%	100% ←(basis)→	100%
1% Si	40,000	46%	14%	20%
2% Si	48,000	52%	11%	13%
3% Si	62,000	58%	8%	9%
4% Si	78,000	47%	....	....

Elongation of the 3½% silicon alloy is approximately equal to that of tough pitch copper rods, and in this matter is superior to mild steel, which it equals in strength and conductivity.

All of the alpha copper solid solutions harden and strengthen rapidly during cold rolling and drawing, with considerable damage to the elongation figures but little to the contraction in area. This effect of cold drawing on some typical alloys has been figured on the basis of percentage of the original properties in the annealed rod, and plotted in the diagram at the right of page 392.

By Ernest E. Thum
Editor Metal Progress

It is seen that "silicon bronze" hardens almost as rapidly as 66-34 brass and proportionately much more than copper or 10% tin bronze, and the damage to the ductility (elongation figure) is less than in brass or copper. Since the base of operations (that is, the physical properties of the hot-rolled rod) is so much higher in the 3¼% silicon alloy, it is obvious that high strength and ductility may be more readily achieved with it than with other common copper alloys. This is indicated in the following table:

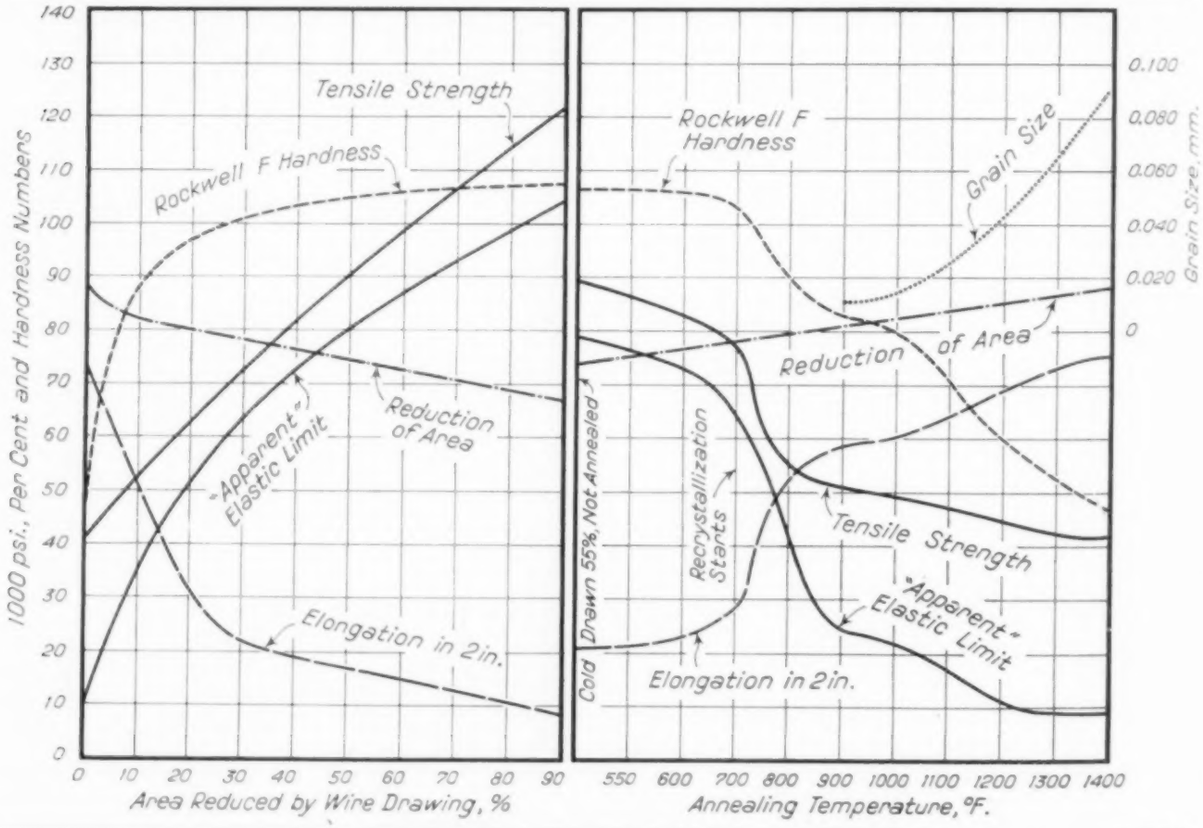
Tensile Properties of Common Copper Alloys

Material	Ultimate Strength	Elongation in 2 In.	Contraction in Area
Annealed Wire Rod			
Copper	33,000	48	75
Brass (66-34)	46,000	63	80
10% tin bronze	62,500	70	..
3¼% silicon	65,000	60	70
Cold Drawn 60% ("Hard Temper")			
Copper	57,500	8	62
Brass	105,000	8	57
Tin bronze	105,000	17	..
3¼% silicon	130,000	17	54

In other words, a moderate amount of cold drawing (4 Brown and Sharpe numbers to "hard temper") will produce much stronger wire in copper-silicon than even in the more expensive tin bronze, and much stronger and more ductile than in either brass or copper. Looked at from another viewpoint, wire drawn to 100,000 psi. ultimate strength will have only 9% elongation in brass, 20% in the tin bronze, and 26% in 3 to 3¼% copper-silicon alloy. Even in this condition the latter has a good figure for contraction of area, and this is one of the best indications of the ability to withstand further cold work.

Representative values for the commercial alloys containing 3 to 3¼% silicon and 2 to 2½% silicon in rods under 1 in. diameter are contained in the two diagrams below. Comparison

Specific Values Showing Effect of Increasing Cold Work on Silicon-Copper Alloy Rods and Wire. Annealing of cold-drawn wire above 700° F. causes recrystallization and large changes in mechanical properties. Diagram on this page is for 2 to 2½% Si, on opposite page is for 3 to 3½ Si, and they are adapted from the Revere Copper & Brass Co.'s booklet on "Herculoy"

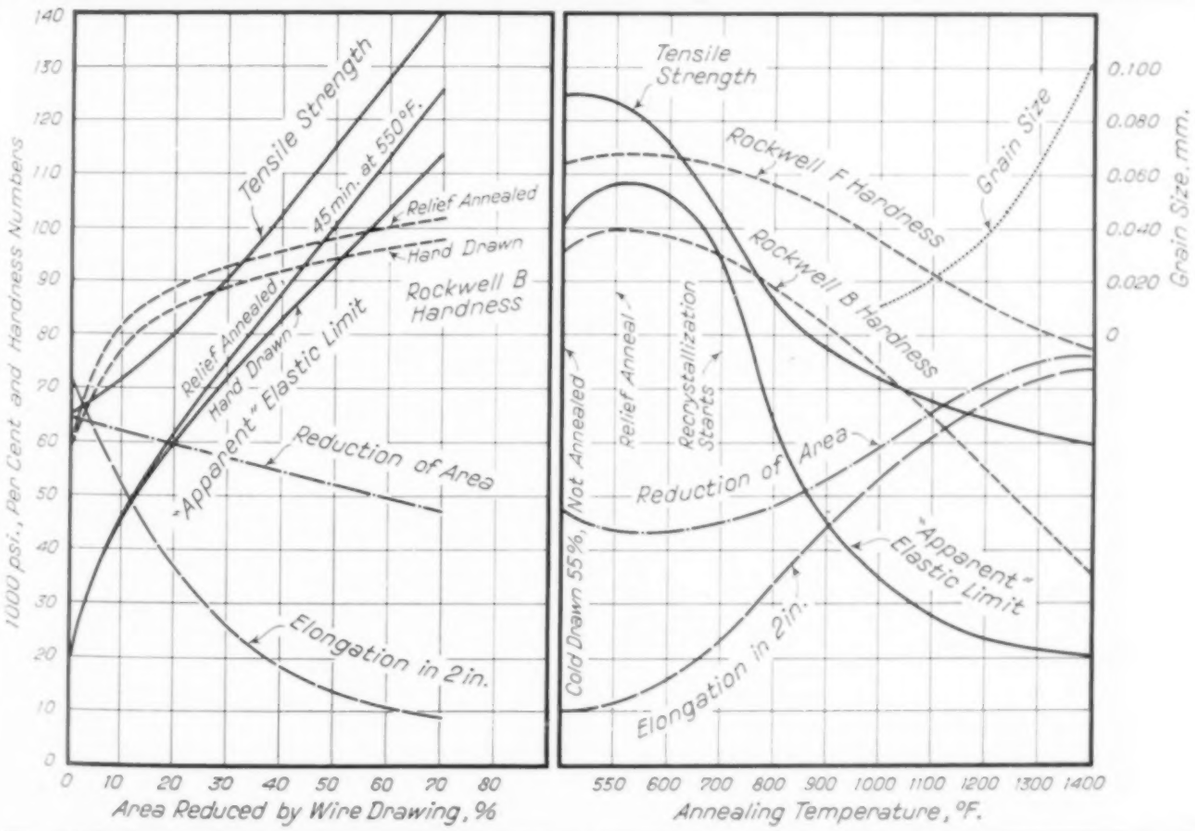


of these two will again indicate that increased silicon will give better tensile strengths without inducing brittleness (that is, the reduction of area and the elastic limit remain high). However, the workability both hot and cold of the lower silicon alloys is better, and for that reason they are more suitable for cold heading or cold forging. Hot forging of the 3% silicon bronze should be done within the range of 1475° to 1200° F., but the alloy is rather stiff even then so that it is not a popular choice for forgings except where unusually high strength and corrosion resistance are necessary in the finished article. Alloys containing about 1½% silicon, in the form of hard-drawn rod, can be cold headed and roll threaded into bolts which will withstand severe abuse without cracking.

The problem of "season cracking" — intercrystalline failure of cold-worked metal caused by mild corrosion — has given trouble in some instances. This is mitigated or avoided as in many other copper alloys by the low temperature anneal to relieve internal stress induced by cold work; it will be observed in the diagram below showing properties of the 3% silicon alloy that 45 min. at 550° F. causes no change in the tensile strength or ductility, but does improve the "elastic limit" and raises the hardness slightly. No difference in the microstructure is observable, and an explanation of the actual mechanism of stress relieving anneal is still in the speculative stage.

Season cracking and stress corrosion are resisted better than by most high strength alloys, as is shown by the diagram on page 394 which contains the results of tests wherein the life of 10-gage wire carrying definite additional tensile stress is measured in an atmosphere of strong ammonia. Life of 3% "silicon bronze," either soft or hard drawn, under these conditions known to induce season cracking, is many times that of other common alloys. If locked-up stresses are suspected, definite tests in ammonia or in the more drastic mercurous nitrate can be used to check up on the efficacy of the proposed finish anneal.

"Dezincification," a type of corrosion that has plagued the high-zinc brasses, is of course



absent because zinc is either totally absent or present in very small amounts.

Higher annealing temperatures alter the physical properties of cold-worked copper-silicon alloys, even before any visible recrystallization and grain growth sets in. Diagrams indicating these changes, on pages 390 and 391, have the general aspect of similar diagrams for the other common copper alloys. It can be appreciated that an infinite number of combinations of properties may be had by proper selection of silicon content, amount of cold reduction, and temperature of final anneal. In practice a "light anneal" would be at about 900° F.; a "full anneal" at 1300° F.

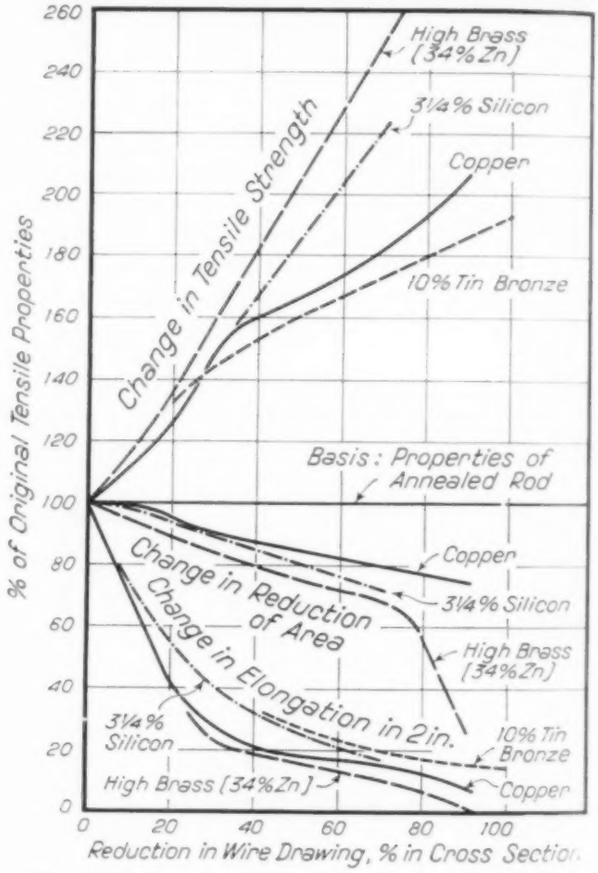
These results for rod and wire are sufficiently general to indicate the properties of plate, sheet and strip. Since the hardness induced by cold rolling is frequently designated by "temper," the following table of equivalents will be useful in translating the data in the diagrams for wire into data for sheet.

Standard Temper Designation	Reduction in B & S Gage Numbers	Plate, Sheet, and Strip; % Reduction in Thickness	Wire; % Reduction in Area
⅛ hard	½	6	11
¼ hard	1	11	21
½ hard	2	21	37
¾ hard	3	29	50
Hard	4	37	60
Extra hard	6	50	75
Spring	8	60	84
Extra spring	10	68	90

The results shown in the diagrams will also vary in minor respects depending on composition — that is, the nature and amount of the third or fourth alloying element. However, they approximate average values for the commercial bronzes. E. Voce, in *Journal* of the British Institute of Metals, 1930-II, page 331, presents ternary diagrams showing the influence of manganese up to 6% on copper-silicons with up to 7% of the latter element. These diagrams were reproduced on page 261 of the last issue. Annealed sheet, tested in the direction of rolling, is improved in tensile strength with more and more manganese up to 1½%. The peak of ductility occurs with 2 to 3% Si and 2 to 3% Mn, although silicon must be over 5% before elongation drops to below 30%.

Mechanical properties and workability of thin sheet and fine wire also depend on the gage. It is more precise to say that, for a given silicon content, the grain size at the "get ready to finish" stage is the most important criterion, and this in turn requires careful control of the rolling or drawing and annealing program up to that point. A get-ready-to-finish grain size of 0.015 mm. appears to give optimum properties to the 3% silicon alloys, especially when cold rolled or drawn two to six numbers hard.

Definite data on strip, sheet and wire should therefore be secured from the manufacturer when accurate figures or guaranteed minima are needed for design.



"Silicon Bronze" Work Hardens as Rapidly as Brass With as Little Damage to Toughness as Tin Bronze

As in other bronzes, there is no definite yield point in the stress-strain curve; it curves almost from the beginning so even the proportional limit and modulus of elasticity are doubtful. For that reason most mills have adopted the convention that the stress at 0.50% elongation should be regarded as the apparent yield

strength. Experience has also indicated that static stresses below this limit will be safely carried.

(In the diagrams on pages 390 and 391 the "apparent elastic limit" has been plotted. This is obtained by metallurgists for Revere Copper & Brass as follows: If a sample is loaded the stress-strain curve is actually curved almost from the beginning, but if the load is moderate and is slowly relieved, the stress-strain curve on relief is practically a straight line returning directly to the origin — that is, there is no permanent set. On reloading to higher and higher values, the up curve retraces its original course, and the down curve returns straight to zero. This continues until the "apparent elastic limit" is passed, whereupon the down curve also becomes slightly curved and does not return to zero — that is, there is a little permanent set. At the "apparent elastic limit" the stress-strain curve of a test to failure on a fresh test piece will also have noticeable increase in curvature, as shown if equal increments of stress are plotted against increments of strain.)

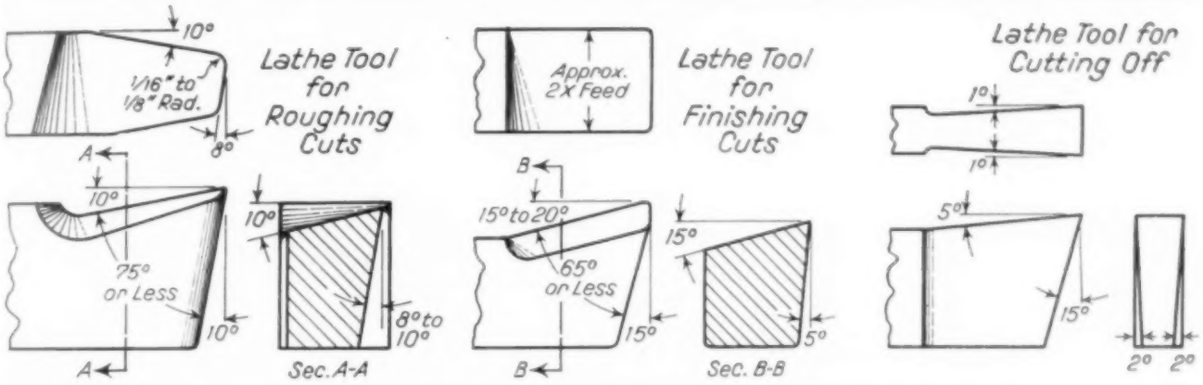
Endurance limit of the copper-silicon alloys is approximately 25% of the ultimate strength. As an instance: 29,000 psi. endurance in extra spring temper strip, relief annealed, with ultimate strength of about 115,000 psi.

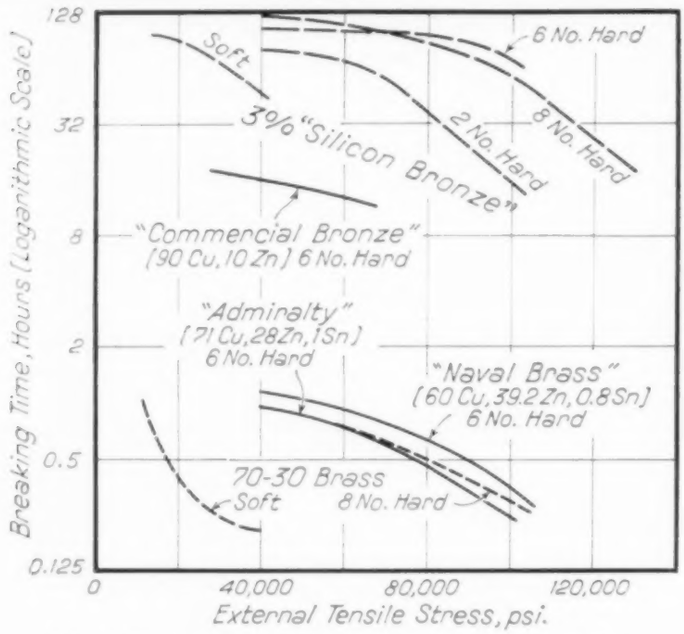
Variants for Special Uses

It has already been remarked that the first non-electrical use of "Duronze" was for cap screws, and this market of fasteners has been highly developed. Being non-rusting, nuts do not freeze to bolts and can be readily backed off when necessary. Nails, bolts, nuts and lag screws for marine exposure, ground water or mine water immersion, sulphite handling equipment in paper mills, pole hardware and outdoor electrical devices are used in large numbers. For many of these the more workable 1½ or 2% alloy is suitable. Threads are readily rolled in, which is fortunate, for so tough an alloy machines with as much difficulty as a low carbon steel, and about one quarter as easily as free-cutting brass.

For the smaller fasteners and other parts ordinarily made on screw machines, a variant with about 0.5% lead is produced. Since as little as 0.005% lead is bad for the hot working properties of these silicon alloys, this freer-cutting variety cannot be hot rolled from the ingot but must be cold rolled into rods, a more difficult and costly process. Lead also gives sufficient brittleness to the chip so it breaks free from the work and tool; its presence makes no noticeable difference in strength or corrosion resistance. Izod impact in rods 2 numbers hard is well over 100 for the unleaded bronze, about 60 for the leaded bronze and only 20 for free-turning brass. However, the application must involve serious requirements, else brass will be good enough, and brass is cheaper than copper-silicon alloys and even in the leaded condition the latter only machines at about 60% the ease of free-cutting brass.

When un-leaded silicon bronzes must be machined, tools with liberal rake such as illustrated are recommended by Bridgeport Brass Co. Plenty of coolant is desirable, a good mix-





Life of Stressed Wire (10 Gage) in Atmosphere of Concentrated Ammonia — Conditions Known to Induce Season Cracking — Is Much Greater for Silicon Bronze Than Other Common Brass Alloys (Chase Brass and Copper Co.)

from hot water storage tanks, range boilers, refrigeration units, air conditioning devices (especially on railway cars where vibration may cause early fatigue failure on weaker alloys), benzol recovery equipment and heavy chemical plant. In the past, pressure vessels for benzol recovery, for instance, were made of steel strong enough for the loads and lined with copper sheet for corrosion resistance — but these linings were difficult to make absolutely tight, and a pinhole leak would be ruinous. Plates of copper-silicon up to ¾ in. thick and weighing 7½ tons are now shipped from Lukens Steel Co. in the hot-rolled condition without removal of mill scale, and are very suitable for any of the modern welding processes — arc, oxy-acetylene or resistance. As emphasized in the first article, the ability of these silicon alloys to be hot rolled and otherwise worked with impunity is one of the reasons they are promoted so vigorously by the brass mills.

Welding Practice

The low thermal conductivity and the high ductility (both hot and cold) are of great advantage in welding the "silicon bronzes." It is easier to put enough heat into the joint to make the weld without having it flow rapidly back into the cold plate, as it does in purer copper, yet the heat flows readily away so that the solidifying metal passes quickly through a "crumbly" and hot-short range 200° F. wide just below the solidus.

Rapid, continuous welding with a small puddle is therefore essential. When this is achieved there is no difficulty with the brittle joints that plague a copper weld. In the latter case the metal, if tough pitch, contains copper oxide which is readily reduced forming steam blowholes, and, if oxygen-free, is easily over-oxidized. The copper-silicon alloys are not only deoxidized and degasified, but contain an excess of silicon, an efficient and cleansing slag former. Whereas an 80% weld in soft copper is something of an achievement, a 90% weld in copper-silicon can be readily accomplished. This means a joint in 3% silicon alloy testing 52,500 psi. in tension, about double the strength of a similar joint in copper. (Naturally the higher

ture being two parts soluble oil, one part kerosene and 10 parts water. Sulphurized oil is best for finishing and drilling; any resulting discoloration if undesirable can be removed by 5% sodium cyanide solution. Drills, taps, reamers and milling cutters should have narrow lands and well polished flutes.

Springs, spring contacts, and varieties of fasteners that require spring properties, are also made in considerable number, thus competing with the old reliable phosphor bronzes. Corrosion resistance, high fatigue limit, and high strength are of importance here. Modulus of elasticity figures are questionable on account of curvature of the stress-strain curve; values quoted are 20,000,000 psi. in tension as hot-rolled and 15,000,000 as hard-drawn rods; in torsion it is approximately 5,500,000 psi. in the hard-drawn condition. Torsional strength is high; the 3% silicon alloy in ¼ in. diameter, spring temper, will twist 0.8 turn per in. before failure against a torque of 25.1 in-lb. Comparative values for manganese bronze are 0.5 turn and 19.5 in-lb. torque.

The real tonnage has developed in plate and sheet for various kinds of tankage. These vary

strengths achieved by cold work are impossible in fusion welds.)

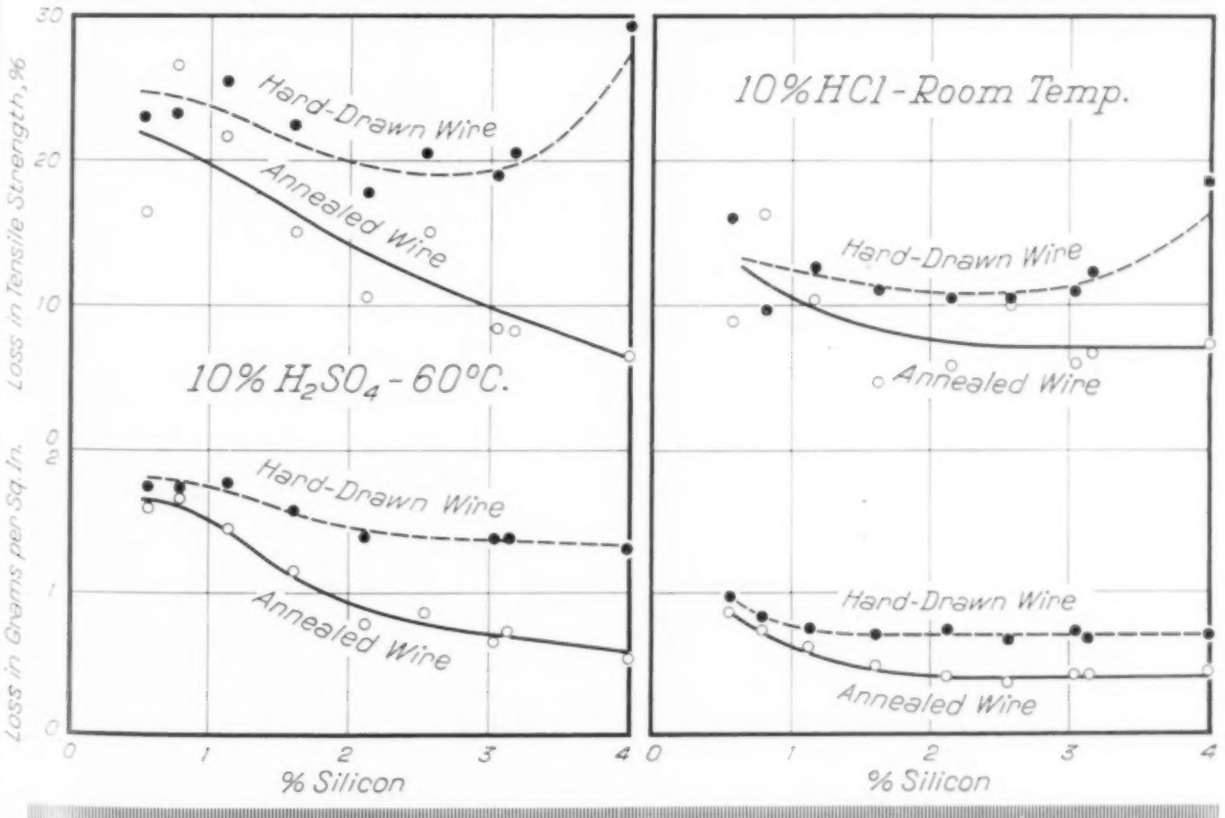
Full advantage of these high strengths cannot now be taken in vessels built under the A.S.M.E. code, for it only permits unit stress of 50,000 psi. in welds of all gages of copper-silicon plate, reduced by the same factors of safety as for steel where corrosion losses have as much to do with the "factors of safety" as indeterminate stresses and variation in workmanship.

In all varieties of fusion welding the abutting edges should be ground free of scale back a distance equal to the thickness of the plate. Regions at and adjacent to the weld must be *clean* of dirt, oxide or acid. Flanged edges are best on thin sheet; from $\frac{1}{16}$ in. to $\frac{3}{16}$ in. plain butt joints may be made with $\frac{1}{16}$-in. opening; thicker plates should be beveled. Grooved copper backing-up strips are helpful.

For oxy-acetylene welding a flux of fused borax and sodium fluoride in water-free alcohol is painted on; a slightly oxidizing flame (10% excess oxygen) and over-size tip are recommended. Filler rods of the same analysis as the base metal or somewhat higher silicon content are suitable. More than $\frac{1}{4}$ in. of metal should not be deposited in a single run; surface slag should be carefully removed before the second run is made. In all multiple-run welding a 4-in. length should be run backward toward the starting edge and then cooled before continuing the work, to reinforce the end against cracking under the thermal stresses.

These new alloys are especially suitable for carbon arc welding if it can be done in a horizontal position. Flanged edges, or abutting edges with rod or strip placed between, can be rapidly melted down into sound joints of first-class appearance. Pointed graphite electrodes are best; direct polarity (work positive) with long arc and high current is essential. (Arc welding is also possible with reversed polarity on preheated plates, but transfer of copper in the electric arc is rather irregular and in large

Effect of Alloy Content on Corrodibility of Everdur (Cu-Si-Mn) in Hydrochloric Acid and in Sulphuric Acid, as Estimated by Loss of Weight and Per Cent Loss in Original Tensile Strength. "Hard drawn" means reduced from 0.365-in. annealed rod to 0.183-in. wire — 6 B & S numbers. (H. A. Bedworth)



globules so that a heavily coated rod is necessary to control the action.) No more than ⅛ in. should be built up with a single pass of the arc. If each layer is cleaned and peened, as called for in the A.S.M.E. Boiler Code, it will recrystallize in the heat of subsequent welding, tensile strength will be raised 7500 psi. and ductility in free bend test increased by 10% in 2 in.

Recommended welding practices, worked out in detail, can be secured from leading manufacturers of the alloy or welding equipment.

Low thermal and electric conductivity of the alloys is of advantage in spot and seam welding, and this is very widely used on the thinner sheets. Excellent results for cooling units in domestic refrigerators have led to the development of cheaper silicon "brasses," of which two are noteworthy: 70:30 plus ½% silicon and 77:23 plus 1% silicon. In the annealed condition the former is not much if any stronger than the simple brass, but the latter has about 57,000 psi. tensile strength. It therefore has considerable extra strength, the corrosion resistance of brass (rather than copper), intermediate cost, and fair weldability.

For it, as well as copper-silicons, the surface condition is critical as regards resistance welding of lapped surfaces. The natural color of the "silicon bronzes" can be buffed into a rich, golden bronze. Exposed to the atmosphere the alloy "antiques," and slowly develops the familiar greenish patina of copper. The alloys are not "stainless," but strongly resist corrosion. At furnace temperatures they oxidize to a black copper oxide, containing its proportion of silica (SiO_2). Remnants of this tenacious silicon oxide will cause irregular fusion in spot welding, and it must be entirely removed from sheets for equipment where one bad weld out of 500 spots would cause a leaky and discarded unit.

Bright annealing in the simply prepared atmospheres suitable for copper will not prevent such oxidation; after such a heat treatment (or open annealing in furnaces with excess fuel gas to limit oxidation) the sheets are pickled in sulphuric acid to remove the black copper oxide, then in dilute hydrofluoric acid to remove the white silica, and then dipped in a solution of sodium dichromate in dilute sulphuric acid to passivate and brighten the surface. Thorough washing is necessary after each treatment. If proper care is taken in annealing, the necessary pickling is so light that subsequent "dry rolling" (pinch pass for surface) is not needed for most applications. For other purposes than welding, a single pickle in 10 to 20% sulphuric acid will produce a pleasing surface, dark red in color.

Seamless tubing of these alloys is readily made (although with the expenditure of more power than for copper). Its use has been rather meager, since in most applications copper tubes have equivalent corrosion resistance and ample strength. An interesting exception is one where strength has really less importance than availability of cast fittings of the same composition — namely, electrical conduits and fittings. Sizable tonnages have been installed in bridge floors in industrial and coastal regions, and also in plants where unusually corrosive condensate may form or where permanent tightness against dusty or explosive atmospheres must be insured.

Corrosion Resistance

It has been already indicated that the silicon bronzes are, in general, equal or superior to electrolytic copper in corrosion resistance. The alloys are not particularly valuable in high temperature service — 600° F. is perhaps the maximum, and 406° F. is the Boiler Code limit for steam. Season cracking due to slight surface corrosion when highly stressed (internally or externally), is much less dangerous than in other common copper alloys. As with copper, corrosion may be greatly accelerated by traces of oxidizing agents; consequently, careful preparatory study using the exact solution to be handled is a requisite.

American Brass Co. issues the following list of chemicals and solutions which have been successfully handled and stored in "Everdur" (Cu-Si-Mn) equipment. All strengths of the chemical are included except as noted.

Acids: Acetic, boric, carbolic, citric (hot or cold), fatty, formic, lactic (hot or cold), oxalic (cold, and saturated at 100° C.), phosphoric up to 50° Bé (hot or cold, but not boiling crude), sulphuric in absence of oxidizing agents (up to 95% cold, up to 50% hot), sulphuric acid vapors, sulphurous, tartaric (hot or cold).

Salts and Salt Solutions: Acetates, alkaline sulphates, aluminum chloride and sulphate, alum (hot or cold), brine (hot or cold), calcium chloride (hot or cold), caustic lime, caustic potash, caustic soda (up to 50% hot or cold), copper sulphates (neutral or acidified, cold), magnesium chloride, milk of lime, sodium acid sulphate pickling solutions (hot or cold), sodium chloride (neutral or acidified), sodium silicate, sulphite solutions in paper mills (hot or cold), zinc chloride (up to 70° Bé, hot or cold), zinc sulphate (hot or cold).

(Continued on page 424)

Sleep SOUNDLY, LITTLE LADY

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Personals

In charge of engineering and development work for Ross-Meehan Foundries, Chattanooga, Tenn.: **Arthur S. Klopf**, formerly assistant professor of mechanical and metallurgical engineering at Marquette University, Milwaukee.

Roy A. Gezelius, formerly associate metallurgist of the Naval Research Laboratory, has been engaged as a metallurgist by the Taylor-Wharton Iron and Steel Co., High Bridge, N. J.

Chosen to deliver the 1939 Howe Memorial Lecture of the American Institute of Mining and Metallurgical Engineers: **H. W. Gillett**, chief technical advisor, Battelle Memorial Institute, Columbus, Ohio.

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Appointed secretary of the Porcelain Enamel Institute: **Charles S. Pearce**, recently assistant director of personnel for the Farm Security Administration.

George H. Thurston has left Judson Steel Corp., where he was assistant chemist and physical tester, and is now employed at Pacific States Steel Corp. of Niles, Calif., as chemist.

Paul M. Steiert, formerly of the Detroit Twist Drill Co., is now chief metallurgist with the Chicago-Latrobe Twist Drill Works, Chicago.

Thomas D. Ketchbaw has resigned from Metal & Thermit Corp. sales department to establish the Industrial School of Welding in Houston, Texas.

H. W. Rathmann, formerly employed by U. S. Engineers Office, St. Paul, Minn., as inspector, is now metallurgist in the research and development department of Vanadium Corp. of America, Bridgeville, Pa.

Metallurgist for the Standard Foundry Co., Worcester, Mass.: **Warren Van N. Baker**, previously foreman of foundries and heat treating for American Steel & Wire Co., South Works.

Transferred from Flint, Mich., to Toledo, Ohio: **C. H. Peters**, district representative for E. F. Houghton & Co.

John Schadler, Jr. is now employed in the technical service division of the Standard Oil Co. of New Jersey, Bayway Refinery, Elizabeth, N. J.

Transferred to Pittsburgh for Carnegie-Illinois Steel Corp.: **William H. C. Webster**, contact representative, bar and semi-finished materials division of the metallurgical department.

Norwood B. Melcher is now a blast furnace apprentice for Columbia Steel Co., Ironton, Utah.

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Youngstown Galvannealed Sheets are "tops" for the most difficult forming and drawing in your press room. The patented fusing process bonds the zinc coating to the base metal, yet both are equally ductile, and severe bends without flaking are perfectly safe. Shown here are washing machine lids. The small illustration shows a curved and rolled edge holding a rubber gasket in place. Note the untouched photo It shows how well and how tightly the Galvannealed finish has held to the base even under this severe treatment. There'll be no trouble here from flaking paint or enamel.
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Producers of GOOD INHIBITORS SUCCESSFULLY for 25 years.

Highland Building Pittsburgh, Pa.

Hydrogen Attack

(Continued from page 366)

instance, a 0.11% carbon steel after exposure to hydrogen for 100 hr. at 100 atmospheres and 750° F. had its original impact figure of 27 reduced to 10.

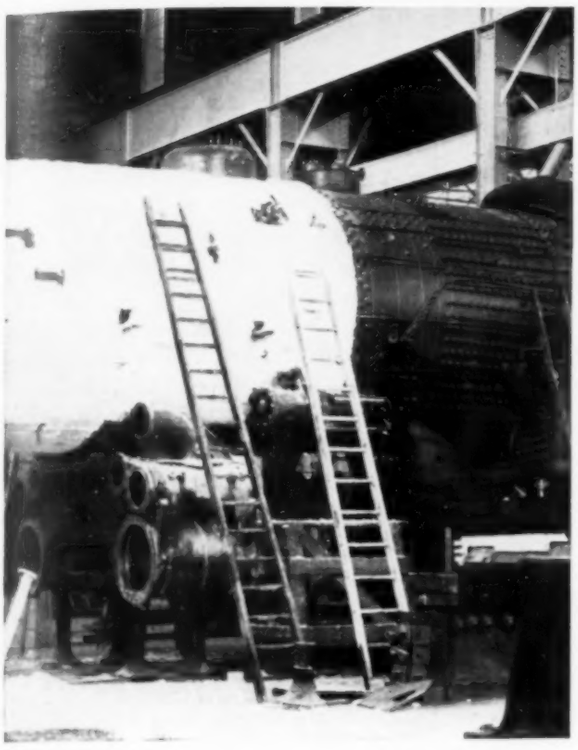
With the formation of the first surface crack the process alters, methane can now escape from the steel, and, on the other hand, hydrogen finds easy access to the interior. This explains the sudden onset of the reaction and the rapid penetration of the decarburization after a definite time during which the steel appears to be resistant. For example, a 0.76% carbon steel showed no apparent damage (decarburization) until 50 to 100 hr. at 750° F. and 300 atmospheres.

In contrast with hydrogen attack, low pressure decarburization penetrates quite regularly and relatively slowly, leaving behind no trace except for the disappearance of pearlite. The test pieces retain their toughness even when decarburization penetrates to the middle of the specimen. Moist or unpurified hydrogen will effect this type of decarburization, but dry, pure hydrogen will not. Decarburization by dry, pure hydrogen at atmospheric pressure does not begin below 1750° F. At 1475° F. its effect is purely superficial, but in moist hydrogen, oxygen is the principal decarburizing agent.

Some extensive work at high pressure was recently published by F. K. Naumann in **Stahl und Eisen**, 1937, Vol. 57, p. 889, and this contained some curves indicating the limiting conditions of temperature and pressure under which there is no hydrogen attack on steels containing 0.11 and 0.24% carbon. These curves are based on tests occupying only 100 hr., but it is stated that 2000-hr. tests give limiting temperatures of stability which are 50 to 70° lower. Even allowing for this, the temperature limits regarded as safe by Naumann are much higher than those of Inglis and Andrews (**Journal, Iron & Steel Institute**, 1933-II, p. 128, 383), who came to the conclusion that mild steel in the condition normally found in a large forging can be guaranteed a long life under hydrogen at 250 atmospheres only if the temperature is maintained below about 300° F. Naumann definitely regards this limit as unnecessarily low. His figures for a 0.77% C steel are:

1000 atmospheres	600° F.
500 atmospheres	650° F.
200 atmospheres	700° F.
100 atmospheres	750° F.
50 atmospheres	900° F.
1 atmosphere	1100° F.

WHO STARTED THE AGE OF STEAM



tion in the moderate temperature (600° F.) field. 85% Magnesia is made from dolomite limestone, chemically converted into magnesium carbonate and combined with asbestos fiber into blocks and pipe insulation. Steam lines, boilers, oil-refinery fractionating apparatus and many other types of industrial equipment are effectively protected against heat waste with this J-M Insulation.

Industry as we know it today began in 1765, the year James Watt developed the first practical steam engine. With this unlimited source of mechanical power at his command, man finally escaped from monotonous, backbreaking methods of doing the world's work. Human energy was directed to more constructive tasks, and during the next century civilization made more progress than in all the ages since the dawn of history.

Watt's engine ran by heat, and it wasted far more than it used. Seeking to improve it, he hit on the idea of wrapping a jacket of wooden strips around the cylinder. This is one of the first known uses of industrial insulation . . . the beginning of the idea of conserving heat and fuel.

For more than a century, however, insulation was not considered important. Fuel was plentiful . . . heat losses from boilers, furnaces and exposed pipes were taken for granted. But as the use of heat in industry broadened into new fields and as industrial processes improved, operating efficiencies and production costs were more closely watched. The vital need for effective insulation was recognized.

Today, wherever heat or refrigeration is employed in industry, insulations are also used. And economical, efficient insulating materials are now available for use throughout the entire range of temperatures used in industry—from far below zero to 3000° F. and more above.

Since its beginning 80 years ago, Johns-Manville has pioneered in the development of a great number of the insulations which industry uses today. Part of the story is told on these pages . . . for detailed information on J-M Insulating Materials and recommendations for the solving of various insulation problems, ask for the J-M Industrial Insulation Catalog. Johns-Manville, 22 East 40th Street, New York, N. Y.

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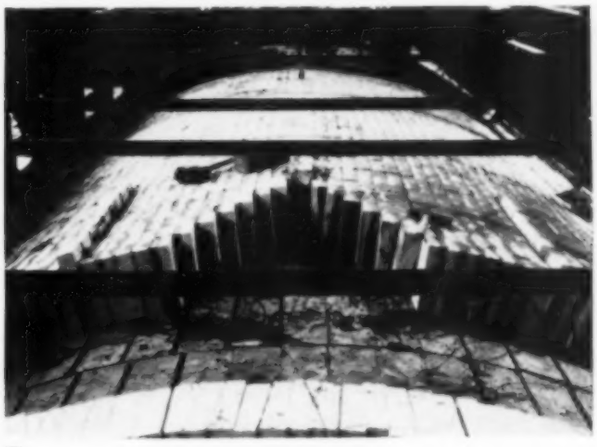
6 This soaking pit wall is being insulated with Superex Block—a highly efficient insulation made of Celite bonded with asbestos fiber. Superex, also manufactured in pipe-covering form, is recognized as the outstanding insulation for superheated steam lines and for conserving fuel and improving performance on slab-heating, annealing and all types of controlled-atmosphere furnaces, producer-gas mains, hot-blast stoves, open-hearth furnaces and regenerators.



7 Other J-M Insulations made from Celite include the well-known Sil-O-Cel materials—Sil-O-Cel Natural and C-22 Brick, Sil-O-Cel Powder and Sil-O-Cel C-3 Semi-Refractory Insulating Concrete. The walls and roof of the normalizing furnace shown above are built entirely of Sil-O-Cel C-22 Brick used as a combination insulation and refractory—a construction which makes possible thinner furnace walls and improved performance. There is a J-M Insulation for every steel-mill requirement.

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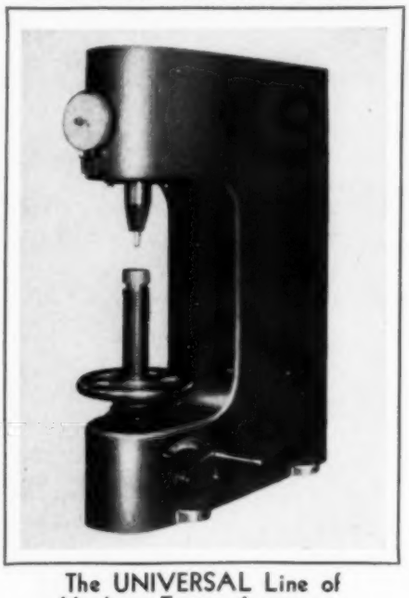

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Once In A Lifetime Mr. Gathmann

. . . or perhaps a little more often, we let a poorly-printed page slip into an issue of Metal Progress. We are sorry it had to happen to your advertisement on the back cover of the March issue. Particularly, when you were trying to show the complete elimination of pipe and segregation in the ingot produced with the combination of a "floating" hot top and a Gathmann big-end-up type mold.

We reproduce this advertisement in this issue, Page 328, as it should have appeared in March. We hope you like it.

The Printers of
Metal Progress

Tubing for Oil Heaters

(Continued from page 372)

18% chromium, 8% nickel with titanium; a stabilized austenitic stainless alloy with excellent strength, corrosion and oxidation resistance.

16% chromium, 13% nickel, 3% molybdenum; adapted from the sulphite paper industry because it showed better strength and corrosion resistance than regular 18-8 stainless.

25% chromium, 20% nickel; austenitic stainless alloy suitable for service requiring extreme oxidation resistance and strength up to 1800° F.

In the class of promising alloy steels for which the commercial service data are as yet incomplete, the following may be mentioned:

Steels containing 2.50 to 4.50% chromium, with molybdenum and vanadium, used successfully for several years in the chemical industry; they presumably have better strength than the Cr-Mo steels.

Steels containing 3.00 to 5.00% chromium, with molybdenum, silicon, and aluminum, exhibit better corrosion and oxidation resistance than regular 5% chromium-molybdenum steel.

5% chromium, 0.50% molybdenum, with columbium; an improved non-hardening steel with good impact strength under all test conditions.

16-13-3 Cr-Ni-Mo with columbium; a prospective welding grade of the austenitic chromium-nickel-molybdenum stainless alloy.

18-8 Cr-Ni with columbium; a stabilized stainless alloy suitable for welding without danger of carbide precipitation.

Selection of a steel from the above list for a particular installation would involve a proper regard for cost. On the contrary, no two steels are likely to be nearly identical in several valuable properties and at the same time differ greatly in price. Hence economy in the choice of steels consists largely in knowing the requirements of the application.

Very probably there will continue to be a large number of alloy combinations tried in an effort to produce cheaper steels having good general properties for oil refinery service at high temperature. A smaller number of special analyses will be developed to solve particular problems in the industry. Confusion as to the merits of the various similar or interchangeable compositions of steel will increase for a while, but in the end the number of alloy steels will be reduced through standardization and only the fundamentally useful analyses will survive.

"TAM Titanium treated" MEANS A BETTER METAL

This DEOXIDIZER *for steels has a marked advantage*

in RIMMING *steel*

Steel entering the mould must contain the *correct* amount of oxide for proper rimming action—too much oxide means excessive effervescence, too little means sluggishness and an inferior ingot.

TAM Ferro Carbon-Titanium, added to the ladle, affords the ideal method for *controlling* oxidation, thereby insuring proper effervescence, and, as a result, insures thick-skinned ingots capable of being rolled into high quality sheets or strips. TAM F. C. T. is an easy and practical ladle addition, and not so concentrated that slight inaccuracies matter in the final result. TAM F. C. T., further, has a valuable fluxing effect. Yet, with all these advantages, TAM F. C. T. entirely departs during rimming action leaving no metallic residue in the solid steel.

Following are practical results obtained on a test run of ingots for galvanized sheets (over 7000 in each lot):

	UNTREATED	TAM F. C. T.
Average yield from ingots	73.93%	77.02%
Sheets showing blisters	4.9	0.07
Sheets showing seams	2.0	0.38
Sheets showing laminations	4.4	0.4

in KILLED *steel*

Here Titanium permits a more complete deoxidation than is possible with manganese and silicon additions, plus a fluxing of slag inclusions which effectively removes impurities. The practical results of Titanium deoxidation are greater soundness and freedom from segregation, and a finer grain-size at higher temperature, together with the separation of more ferrite in microstructure, and better impact resistance and ductility. In certain Killed Steels, Titanium has the beneficial effect of converting soluble nitrides present into insoluble titanium nitride, and thereby preventing embrittlement which nitrogen might cause.

Below is a typical example of the effects of titanium treatment:

BASIC OPEN-HEARTH CAST STEEL
(10 heats averaged for each value)

	UNTREATED	TITANIUM
Yield Point, *lbs. per sq. in.*	36925	42695
Tensile Strength, *lbs. per sq. in.*	71635	76870
Elongation in 2 in., *per cent*	30.1	28.5
Reduction of Area, *per cent*	45.8	50.2

Let a TAM Development Engineer explain more fully!

THE TITANIUM ALLOY MANUFACTURING CO.

TAM Zirconium Titanium Products

General Offices and Works NIAGARA FALLS, N. Y., U. S. A. Executive Offices 111 BROADWAY, NEW YORK CITY

Representatives for the Pacific Coast BALFOUR, GUTHRIE & CO., San Francisco, Los Angeles, Portland, Seattle, Tacoma

Representatives for Canada RAILWAY & POWER ENG. CORP., LTD., Toronto, Montreal, Hamilton, Winnipeg, Vancouver, Sydney

Representatives for Europe T. ROWLANDS & CO., LTD. 23-27 Broomhall St., Sheffield, England

When you fabricate machine parts that are exposed to severe wear or heavy stresses, you can obtain a practical combination of physical qualities by using B & L Cold Finished OPEN HEARTH SCREW STOCK.

This carefully made steel is well developed in machining character to give you economical production on automatic screw machines . . . resulting in smooth, clean-cut, finished parts.

It gives good response to carburizing, cyaniding or liquid surface hardening, where you want to insure a file-hard wear-resistance surface . . . with a good ductile core condition.

Reduce your field service failures by using this modern machining-carburizing steel . . . it is available in standard grades for a wide range of applications.

Ask our representative for details, or write us direct.

B L

OPEN HEARTH SCREW STOCK

•

ACCURATE UNIFORM

•

TYPICAL OPEN HEARTH GRADES

SAE 1115
SAE 1120
SAE X-1314
SAE X-1315
SAE X-1330
SAE X-1335
SAE X-1340

Cold Drawn Bars - Ground Shafting - Alloy Steels

BLISS & LAUGHLIN, INC.
HARVEY, ILL. *Sales Offices in all Principal Cities* BUFFALO, N.Y.

Copper-Silicon

(Continued from page 396)

Organic and Food Materials: Acetone, alcohols, beer (except for long storage), carbon tetrachloride (except moist and hot), cresol, gasoline, organic salts and solutions, phenol, sugar solutions, tanning liquors (cold).

Miscellaneous: Alkaline inks, commercial fertilizers, chlorine (dry), gas (illuminating or natural), sewage, sulphur dioxide, water (corrosive industrial and natural water, potable water, hot or cold sea water).

In Technical Publication No. 189, A.I.M.E., 1929, H. A. Bedworth reports on the influence of silicon (plus one third its quantity of manganese) in copper on corrosion resistance to hydrochloric acid and sulphuric acid. Both were in 10% solution, the latter at 60° C. Alternate immersion — 90 sec. in and 90 sec. out in air — accelerated the action by complete aeration of the film of corroding liquid. The test was stopped after 216 hr. and loss of weight and tensile properties determined. No pitting occurred. His results, summarized in the adjoining graphs, show that 2% silicon plus 0.7% manganese is sufficient to achieve maximum resistance of annealed rods to hydrochloric acid, but double as much alloy should be used to resist hot sulphuric. Both acids affect the tensile strength of hard-drawn alloys containing more than 3% silicon plus 1% manganese, which increased activity is thought to be due to small, undissolved particles of grayish blue Mn_2Si, possibly the X constituent of Voce's ternary diagram (March issue, page 261).

Work done in the laboratories of Union Carbide and Carbon Corp. by M. G. Corson indicates that silicon has a solubility of 6.7% in copper at 1400° F., considerably larger than at room temperature. Arguing that silicon improves the corrosion resistance of copper by the formation of protective oxides, and that this will be more effective as the content in true solid solution increases, he proposes the quenching of such a high silicon alloy after a homogenizing heat treatment at 1400° F. (See *The Iron Age*, 1927, p. 353.) Such material has not yet been marketed, as the advantages do not seem to warrant the manufacturing and fabricating difficulties, which would obviously be considerable.

WHAT A GAS MASK IS TO A SOLDIER

HOT GALVANIZING

IS TO IRON AND STEEL

Where metal products are put to hard work under the constant attack of corrosive vapors, Hot Dip Galvanized Iron and Steel will serve more efficiently, longer and at less cost . . . This is a proved fact . . . Remember that zinc is the most practical protection known to metallurgy . . . Remember that hot dipping makes the heavy shell of zinc a part of the product itself. Patronize members of this Association . . . Our insignia is your guarantee of a thick, durable coating of approximately two and one-half ounces of zinc per square foot of surface and of flawless workmanship in applying it. Write for our new specification folder—a complete analytical guide for buying galvanizing. Address American Hot Dip Galvanizers Association, Inc., American Bank Bldg., Pittsburgh, Pa.

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PROTECTED BY GENUINE
HOT-DIP
GALVANIZING
AMERICAN HOT DIP GALVANIZERS ASSOCIATION INC.

BUY FROM THESE QUALIFIED MEMBERS

Acme Galvanizing, Inc., Milwaukee, Wis.
Acme Steel & Malleable Iron Works
Buffalo, N. Y.
American Tinning & Galvanizing Co.
Erie, Pa.
Atlantic Stamping Co., Rochester, N.Y.
Buffalo Galvanizing & Tinning Works, Inc.
Buffalo, N. Y.
Columbian Steel Tank Company
Kansas City, Mo.
Diamond Expansion Bolt Company, Inc.
Garwood, N. J.
Enterprise Galvanizing Co., Philadelphia, Pa.
The Fanner Mfg. Company, Cleveland, Ohio
John Finn Metal Works, San Francisco, Cal.
Thomas Gregory Galvanizing Works
Maspeth, N. Y.
Hanlon-Gregory Galvanizing Company
Pittsburgh, Pa.
The Hodell Chain Company, Cleveland, Ohio
Independent Galvanizing Co., Newark, N. J.
International Derrick & Equipment Co.
Columbus, Ohio
Joslyn Co. of California, Los Angeles, Cal.
Joslyn Mfg. & Supply Co., Chicago, Ill.
L. O. Koven & Brother, Inc., Jersey City, N. J.
Lehigh Structural Steel Co., Allentown, Pa.
Missouri Rolling Mill Corp., St. Louis, Mo.
The National Telephone Supply Co.
Cleveland, Ohio
Penn Galvanizing Co., Philadelphia, Pa.
Riverside Foundry & Galvanizing Co.
Kalamazoo, Mich.
San Francisco Galvanizing Works
San Francisco, California
The Sanitary Tinning Co., Cleveland, Ohio
Standard Galvanizing Co., Chicago, Ill.
Wilcox, Crittenden & Company, Inc.
Middletown, Conn.
The Witt Cornice Co., Cincinnati, Ohio

Who's Who in This Issue

Nine years in the technical service department of New Jersey Zinc Co. concentrating on die casting problems forms a solid background for **W. W. Broughton's** Western Metal Congress paper on zinc alloy die castings. Broughton is a mechanical engineer as well as a practical metallurgist, having graduated from Stevens Institute of Technology in 1922. He is a member of the American Society of Mechanical Engineers and of the American Society for Testing Materials.

J. Richard Goldstein did not have far to go to present his paper on metals used in the aircraft industry before the Western Metal Congress in Los Angeles last month (printed on page 357). Possessor of a Master of Science degree in aeronautical engineering from the Daniel Guggenheim School of Aeronautics at California Tech, he is research engineer for Douglas Aircraft Co., Santa Monica, Calif. Goldstein is not, however, a native Californian, but was born and educated in Rochester, N. Y., graduating from University of Rochester as a mechanical engineer in 1932.

The perennially interesting subject of austenitic grain size has recently been tackled by two young metallurgists with Universal-Cyclops Steel Corp. Senior author of the article describing a new technique for grain size study is **Rufus W. Snyder**, alumnus of Michigan State College (B.S. in Engineering, 1922) and of Pennsylvania State College (M.S. in Metallurgical Engineering, 1925). Six and a half years in the metallurgical laboratory of American Steel and Wire Co. preceded his affiliation with Universal-Cyclops in 1932.

At the time that Rufus Snyder joined Universal-Cyclops, **Howard F. Graff** was graduated from Case School of Applied Science. For the two preceding years his extra-curricular activities had included employment as assistant to the metallurgist, Cleveland Wire Works, Incandescent Lamp Department, General Electric Co. This position he continued to hold until 1935, when he entered the Universal-Cyclops laboratory as research metallurgist.

Harry K. Ihrig began his search for a corrosion resistant material while he was employed in the gas and oil industry in the 20's. His career started on the Pacific Coast doing research and engineering work following receipt of a Ph.D. from University of California in 1923. Subsequent connections as consulting engineer, first with Ralph E. Davis, Inc., and later with European Gas and Electric Co., took him to New York and Pittsburgh and to Europe respectively. Experiments with silicon impregnation (described on page 367) began when he was a member of the consulting firm of Butterworth and Ihrig in Columbus, Ohio, and were brought to successful fruition in recent years at the plant of Globe Steel Tubes Co., Milwaukee, Wis., where Dr. Ihrig now serves in the capacity of director of laboratories.

W. W. Broughton

Rufus W. Snyder

Howard F. Graff

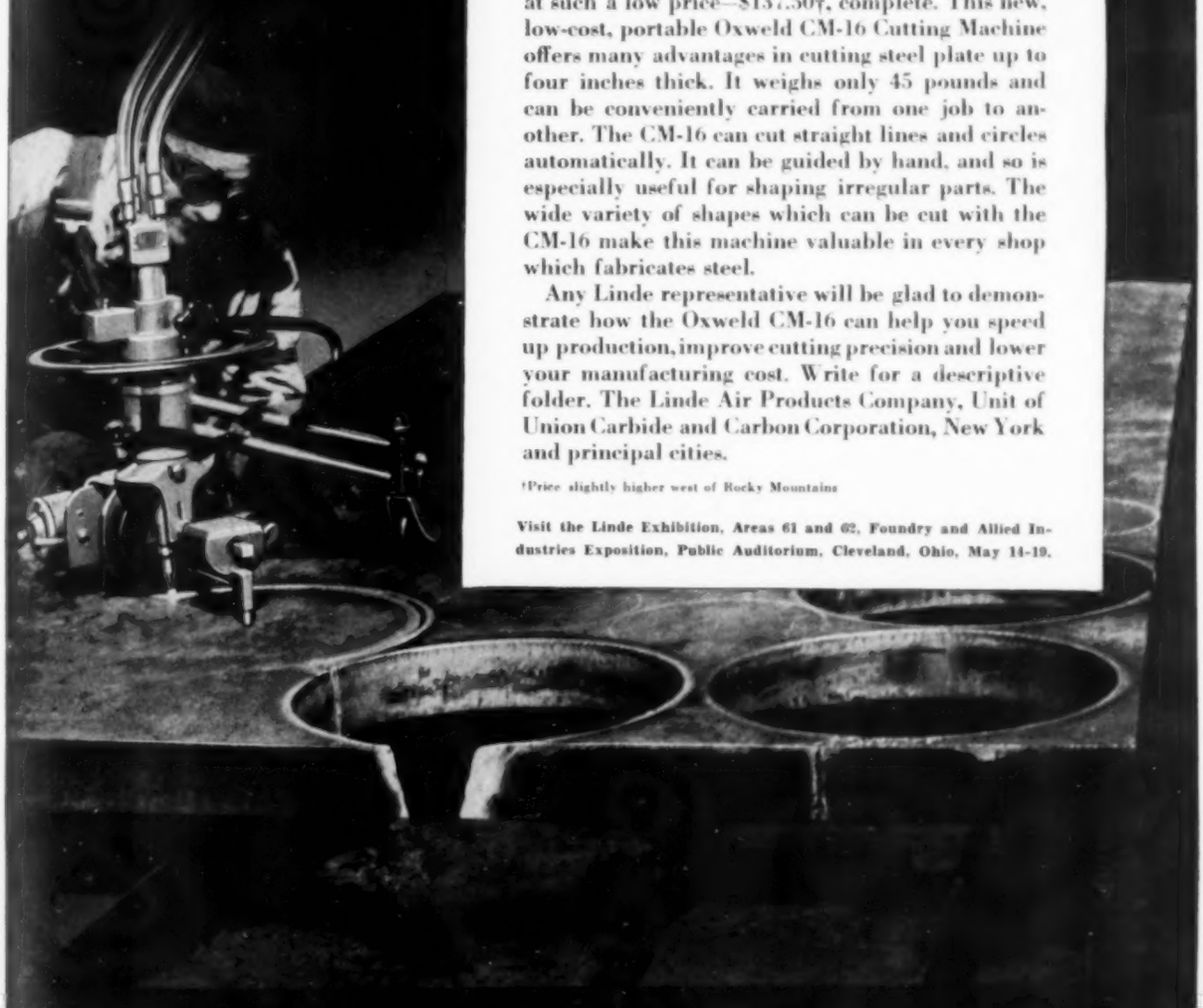
J. Richard Goldstein

Harry K. Ihrig

THE OXWELD CM-16

A portable Oxy-Acetylene Cutting Machine

. . . at a new low price - $137.50



NEVER before has it been possible to buy a motor-driven oxy-acetylene cutting machine at such a low price—$137.50†, complete. This new, low-cost, portable Oxweld CM-16 Cutting Machine offers many advantages in cutting steel plate up to four inches thick. It weighs only 45 pounds and can be conveniently carried from one job to another. The CM-16 can cut straight lines and circles automatically. It can be guided by hand, and so is especially useful for shaping irregular parts. The wide variety of shapes which can be cut with the CM-16 make this machine valuable in every shop which fabricates steel.

Any Linde representative will be glad to demonstrate how the Oxweld CM-16 can help you speed up production, improve cutting precision and lower your manufacturing cost. Write for a descriptive folder. The Linde Air Products Company, Unit of Union Carbide and Carbon Corporation, New York and principal cities.

†Price slightly higher west of Rocky Mountains

Visit the Linde Exhibition, Areas 61 and 62, Foundry and Allied Industries Exposition, Public Auditorium, Cleveland, Ohio, May 14-19.

Everything for Oxy-Acetylene Welding and Cutting

LINDE OXYGEN • PREST-O-LITE ACETYLENE • OXWELD APPARATUS AND SUPPLIES FROM LINDE UNION CARBIDE

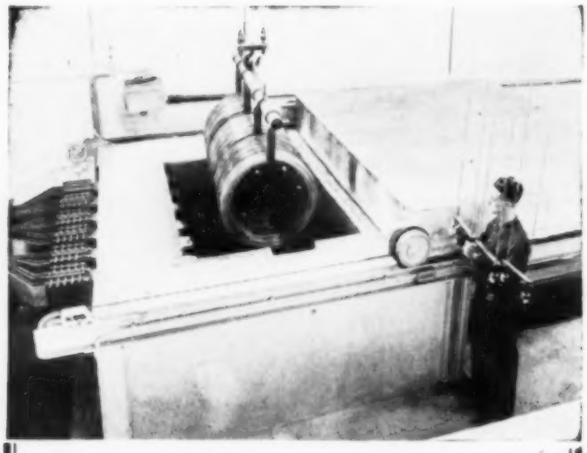
PRODUCTS OF UNITS OF UCC UNION CARBIDE AND CARBON CORPORATION

The words "Linde," "Prest-O-Lite," "Oxweld" and "Union" used herein are registered trade-marks.

Special Alloy Steel Plan Aids Steel Treater . . . .

Ryerson Certified Alloy Steels are all from selected heats that meet an ideal specification—a "specification within a specification" that assures year after year uniformity. All Ryerson Certified Alloys are analyzed and tested in advance. Special data sheets are prepared and sent with every shipment, no matter how small. With these data sheets, the heat treater knows the properties and characteristics of the steel. He does not have to test. He does not take chances and he does not have to in less time. There are many other advantages. Let us tell you the complete story. Write for Booklet. Joseph T. Ryerson & Son, Inc. Plants at: Chicago, Milwaukee, St. Louis, Cincinnati, Detroit, Cleveland, Buffalo, Boston, Philadelphia, Jersey City.

RYERSON Certified STEELS



We have recently made some radical improvements in our Lavite heat treating process. It is now possible with the new Triple A Lavite to get a highly metallic lustre finish from an oil, air or solution quench and the film of Lavite washes off easily. Those who have seen the new process work exclaim that as a heat treating process it leaves nothing to be desired. Let us send you details.

THE BELLIS HEAT TREATING COMPANY

BRANFORD, CONNECTICUT

Originators of

Lavite Electric Furnaces and Heat Treating Baths

Steel Hardenability

(Continued from page 376)

son is obviously that steel **A** had its rapid increase in amount of pearlite (sudden drop in hardness) at a slightly smaller diameter than did steel **B**. But again, when this restricted range of sizes is exceeded, the steels once more show similarity. We may, therefore, summarize this behavior by saying that if steels have similar hardenability, the hardness distribution in quenched pieces will be quite similar below the critical size or above the critical size, but in the neighborhood of the critical size the differences in hardenability are exaggerated.

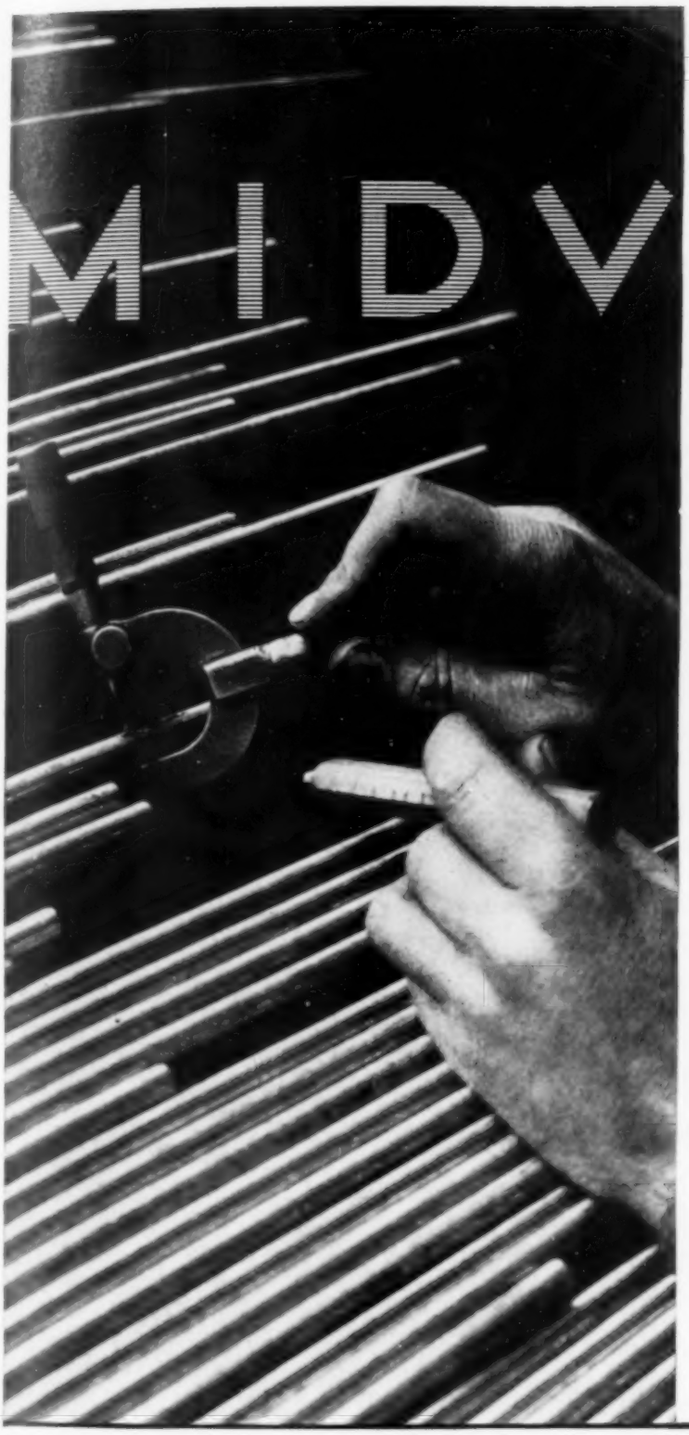
The judging of hardenability by center hardness in a quenched bar thus becomes more useful if there is further knowledge of the hardness distribution, particularly as it is related to the critical size.

Fracture Tests

We may also consider this whole series of behaviors in relation to fracture tests, widely used to determine "depth of hardening." It is of interest here to discuss the nature of the hardened rim and the unhardened core. On page 376 are photographs of two bars of steel showing an unhardened core as it appears in the fracture of a round bar, and below each photograph is the hardness distribution. We see that the so-called "hardened rim" is not by any means hardened fully, for if we proceed from the surface toward the center of the bar, we find that there is a considerable drop on the hardness curve before the hardened rim is passed. This is illustrated further in the third view in the series on page 376 which shows the fracture of a piece having no unhardened core, yet the bar is quite measurably softer at the center than it is at the outside.

The transition on the fracture from rim to core is at the position where there is a considerable and sudden drop in hardness, corresponding for example to the position **X** in the first figure. We may go even further. Experience has shown that the transition from rim to core is at about the position where the steel consists of about half pearlite and half martensite, and we realize from previous discussion that this is the position of most rapid formation of pearlite. Indeed, this very behavior is the thing that makes it possible to read the depth of hardening, for at this point is found the most sudden change in the proportion of pearlite, so that the mechanical behavior of the steel while it is being fractured changes quite suddenly at this

(Continued on page 436)



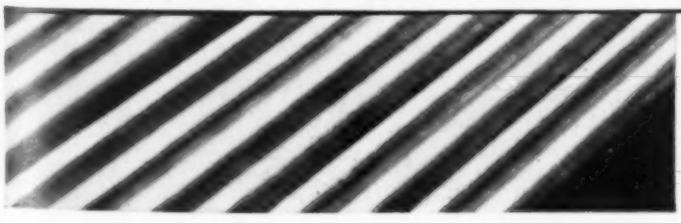
Precision . . . in bars, forgings or castings

Precision is a three-way matter at Midvale. First, there is precision of formula for the steel itself—established in the Midvale laboratory, maintained by rigid and constant supervision. Second, there is precision of size and shape—essential in today's micrometer fittings. And third, there is the precision of quality—the precision that protects you from those flaws and faults that can be so disastrous when the particular bar, forging or casting is put to its final use.

One word has a hard job describing the unusual experience and thoroughness that go into a Midvale product. But if we must boil it down to one word that can symbolize the desirable qualities, the added protection to you in your own shops and products, the keynote of Midvale production is —precision.

THE MIDVALE COMPANY • NICETOWN • PHILADELPHIA

OFFICES: *New York* • *Chicago* • *Pittsburgh* • *Washington* • *Cleveland* • *San Francisco*



A-B Specimen Cutting Machines
A-B Bakelite Presses
A-B Specimen Grinders
A-B Specimen Polishers
A-B Specimen Holders
Metallographic Microscopes of Bausch & Lomb, Leitz and Carl Zeiss

Mounting Press

Hundreds of Metallurgists using this press never again would go back to the old melting pot and ladle method for mounting metal specimens.

Adolph I. Buehler
OPTICAL INSTRUMENTS • METALLURGICAL APPARATUS
228 NORTH LA SALLE ST. •• CHICAGO ILL.

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TOOL STEEL

SUPERDIE
High Carbon, High Chromium

- High Production Die Steel
- Oil or Air Hardening
- Non-Deforming
- High Hardness for Wear Resistance

It pays to use Good Tool Steel.

COLUMBIA TOOL STEEL COMPANY
MAIN OFFICE AND WORKS
500 E. 14TH STREET, CHICAGO HEIGHTS, ILLINOIS

Steel Hardenability

(Continued from page 432)

point, and this is true also of its etching behavior in etching a polished cross section. It may be remarked further that the more pronounced the change in proportion of pearlite, the easier is it to read depth of hardening by the fracture or by the etching method, and further that with some steels and with some sizes the hardness gradient is more gradual and causes difficulties in reading the depth of hardening by these methods.

Finally, it should be pointed out that the depth of hardening as judged by the fracture is sensitive in the neighborhood of the critical size, for the same reasons as were discussed with respect to the hardness curves. Thus, if the two steels A and B discussed above were examined in 1-in. size, they would appear alike, because neither of them would show an unhardened core. If, however, they were examined in 1⅛-in. size, there would apparently be a substantial difference, since steel B would be "hardened throughout," whereas steel A would have a substantial unhardened core. By contrast again, if they were examined in the 1½-in. size, they would again appear more nearly alike, since they would then both have an unhardened core of considerable size.

Need for Quantitative Knowledge

An attempt has been made to discuss some of the factors encountered in measuring hardenability quantitatively. In a qualitative way it is known broadly that hardenability is affected profoundly by various elements. Thus it is known that carbon, while it affects maximum potential hardness, affects hardenability as well, and that the various alloying elements likewise affect hardenability, and in varying degrees. It is known further that grain size also has a profound effect on hardenability. It remains for future work to determine the precise quantitative effects of these various factors on hardenability, taking into account the behaviors which have been discussed here.